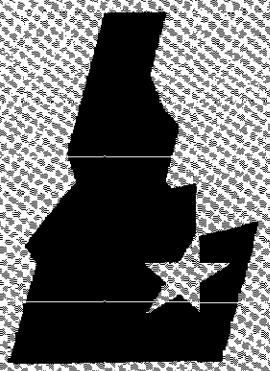
THE CONTENTS OF THIS
DOCUMENT ARE THE HIGHEST
QUALITY OBTAINABLE
INITIAL BAE DATE 3/21/91

EGG-ER-8644
October 1989



Idaho
National
Engineering
Laboratory

Managed
by the U.S.
Department
of Energy

INFORMAL REPORT

CONCEPTUAL MODEL AND DESCRIPTION OF THE AFFECTED ENVIRONMENT FOR THE TRA WARM WASTE POND (WASTE MANAGEMENT UNIT TRA-03)

L. C. Hull

EG&G Idaho

Work performed under
DOE Contract
No. DE-AC07-76ID01570

EGG-ER-8644

CONCEPTUAL MODEL AND DESCRIPTION OF THE AFFECTED ENVIRONMENT FOR THE TRA WARM WASTE POND (WASTE MANAGEMENT UNIT TRA-03)

L. C. Hull

Published October 1989

Idaho National Engineering Laboratory
EG&G Idaho, Inc.
Idaho Falls, Idaho 83415

Prepared for the
U.S. Department of Energy
Idaho Operations Office
Under DOE Contract No. DE-AC07-76ID01570

ABSTRACT

Chemical and radioactive liquid wastes from TRA have been disposed of to percolation ponds and an injection well. Liquid radioactive wastes have been disposed of to the Warm Waste Pond, along with approximately 11,000 kg of hexavalent chromium. Approximately 14,000 kg of hexavalent chromium were injected directly into the Snake River Plain aquifer between 1964 and 1972 via the TRA Disposal Well.

Most of the metallic and radioactive contaminants in Warm Waste Pond sediments are within 2 to 4 ft of the bottom of the 1952 and 1957 cells. Almost all of the chromium discharged to the pond is still in the pond sediments. Chromium concentrations in the part of the deep perched water zone receiving water from the Warm Waste Pond exceed drinking water standards suggesting continued leaching of chromium from pond sediments. Well USGS-65, completed in the regional aquifer immediately downgradient from TRA, contains high concentrations of tritium and chromium, and is the only aquifer well at TRA in which Co-60 has been detected. No other aquifer wells at TRA show similar levels of contamination.

Plumes of chromium and tritium extend to the south and southwest of TRA in the aquifer. The estimated quantity of chromium in the aquifer is 14,000 kg, which balances well with the estimated 14,000 kg disposed of into the TRA Disposal Well. Elevated concentrations of chromium in the aquifer at the RWMC are the right distance and direction from TRA to have originated at TRA.

EXECUTIVE SUMMARY

The Test Reactor Area (TRA) located at the Idaho National Engineering Laboratory (INEL) houses high neutron flux test reactors which have been used to conduct engineering and materials tests since 1952. Chemical and radioactive liquid wastes have been disposed of to percolation ponds and an injection well. All liquid radioactive wastes have been disposed of to the Warm Waste Pond. The major radionuclides of concern are Co-60, Cr-51, Cs-137, Sr-90, and tritium. Hexavalent chromium was used as a corrosion inhibitor in reactor cooling water loops from 1952 to 1972. Approximately 11,000 kg of chromium were disposed of to the Warm Waste Pond between 1952 and 1964. Approximately 14,000 kg of chromium were injected directly into the Snake River Plain aquifer between 1964 and 1972 via the TRA Disposal Well. Two other possible sources of radionuclide and chromium contamination are a leak in a retention basin and breaks in the pipeline leading to the Warm Waste Pond.

The geology at TRA consists of alternating layers of basalt lava flows and sedimentary interbeds. The most recent sedimentary layer is the surficial Big Lost River Alluvium, which is about 50 ft thick. There is a low permeability sedimentary layer at a depth of about 150 ft below the land surface. The alternating layers of sediment and basalt extend to a depth of at least 2000 ft.

Water discharge to surface ponds at TRA (approximately 0.75 million gal/day) percolates downward through the surficial alluvium and basalts. Downward movement is impeded by the low permeability layer at a depth of 150 ft. Water builds up on top of this low permeability layer forming a perched water table of about 400 acres in size. Water is pushed downward through the low permeability layer by the higher hydraulic gradient created by the perched water table. It then continues to move downward reaching the Snake River Plain Aquifer 7 to 8 months after disposal on the surface.

The Snake River Plain Aquifer is one of the most prolific aquifers in the world with a transmissivity on the order of 2 million gal/day/ft. The

average gradient across the southern INEL is approximately 2 ft/mile to the southwest. Calculated and measured flow rates range from 4.5 to 11 ft/day. The thickness of the active portion of the aquifer is estimated to between 250 and 400 ft.

Sampling of Warm Waste Pond sediments to a depth of 10 ft shows that most of the metallic and radioactive contaminants are within 2 to 4 ft of the bottom of the pond. Thus, there has been significant attenuation of contaminants immediately beneath the pond. Calculation of the total mass of chromium in sediments beneath the pond indicates that almost all of the chromium discharged to the pond is still in the pond sediments.

Chromium concentrations in the western portion of the deep perched water zone exceed drinking water standards. This is a part of the perched water zone actively receiving water from the Warm Waste Pond. These elevated concentrations suggest continued leaching of chromium from pond sediments. Areas of the deep perched water zone recharged by the Cold Waste Pond have been flushed of previously high chromium concentrations. Low levels of radionuclides are also detected in the deep perched water zone indicating downward migration from the pond or the leak in the retention basin.

Well USGS-65 is completed in the regional aquifer immediately downgradient from TRA. Water from this well contains high concentrations of tritium and chromium, and is the only aquifer well at TRA in which Co-60 has been detected. These chemical characteristics are not confirmed by other aquifer wells at TRA, which suggests a unique hydrogeologic setting. However, because such elevated chromium concentrations (5 times drinking water standards) have been measured in the aquifer, it is necessary to determine the causes for the elevated levels in order to understand or remediate the situation.

Plumes of chromium and tritium extend to the south and southwest of TRA in the aquifer. The estimated quantity of chromium in the aquifer is 14,000 kg, which balances well with the estimated 14,000 kg disposed of

into the TRA Disposal Well. A balance for tritium cannot be readily calculated because much of the tritium in the aquifer originated at the Idaho Chemical Processing Plant (ICPP).

Elevated concentrations of chromium in the aquifer at the RWMC (20 to 50 μg/L) are about the right distance and direction from TRA to have originated at TRA. Because the highest chromium concentration measured near the RWMC is 50 μg/L (the drinking water standard) and because the extent of the area of elevated chromium concentrations near the RWMC is poorly delineated, it is possible that concentrations of chromium in excess of the drinking water standard exist in the aquifer near the RWMC.

CONTENTS

FIGURES

TABLES

CONCEPTUAL MODEL AND DESCRIPTION OF THE AFFECTED ENVIRONMENT FOR THE TRA WARM WASTE POND WASTE MANAGEMENT UNIT TRA-03

INTRODUCTION

This report is part of the remedial investigation of the Test Reactor Area (TRA) Warm Waste Pond (Waste Management Unit TRA-03) at the Idaho National Engineering Laboratory (INEL). The release of radioactive and hazardous constituents from this site has been identified. The waste management unit is being evaluated according to the corrective action requirements specified in the Consent Order Compliance Agreement (COCA) between the Environmental Protection Agency, Region X (EPA), the State of Idaho, and the Department of Energy, Idaho Operations Office (DOE-ID). DOE-ID has agreed to implement those steps necessary to achieve and maintain compliance with the Resource Conservation and Recovery Act (RCRA) and other applicable regulations.

Results of the remedial investigation, together with historical data, will be used to characterize the rate and extent of migration of hazardous and/or radioactive constituents released to the environment from the TRA Warm Waste Pond and associated piping and retention basins. The potential health and environmental impacts of any known or potential releases will be analyzed to determine if corrective action is warranted at the pond. This report summarizes the known geologic, hydrologic, environmental, and waste inventory data concerning the Warm Waste Pond.

Purpose

The objectives of this report are to provide background information on the physical setting, define the affected environment, demonstrate nature and extent of contamination, and delineate migration pathways for the TRA Warm Waste Pond. To describe the physical setting, information is compiled on the geology, groundwater hydrology, vadose zone hydrology, and surface water hydrology. Data on ecologic and human receptors are

presented to describe the affected environment. Waste inventory data, as well as results of soil and water sampling activities, are presented to describe the nature and extent of contamination. The data are compiled into a conceptual, or descriptive, model of the site to describe the mechanisms and pathways for migration of contaminants. The existing data are evaluated for completeness to identify areas where additional characterization data are needed to perform the risk assessment.

Site Description

The INEL (Idaho National Engineering Laboratory) was established in 1949 by the U. S. Atomic Energy Commission to build, operate, and test various nuclear reactors, fuel processing plants, and support facilities with maximum safety and isolation. Fifty-two reactors have been constructed to date; thirteen are still operable. In addition, the INEL supports other government-sponsored projects, including energy, defense, environmental, and ecological research. The INEL covers about 890 $miles^2$ of the eastern Snake River Plain in Southeastern Idaho (Figure 1).

TRA is located in the southwestern portion of the INEL north of the Big Lost River (Figure 2). The facility houses high neutron flux nuclear test reactors. The TRA Warm Waste Pond (Waste Management Unit TRA-03) is located approximately 200 ft east of TRA and outside the security fence (Figure 3). At various times in the past, the TRA Warm Waste Pond was used for disposal of reactor cooling water, radioactive waste water, and regeneration solutions from ion exchange columns.

History of Liquid Waste Disposal

Chemical and radioactive wastes are generated from scientific and engineering research at TRA. Although extracted and treated, the wastes still contain some low-level radioactive and chemical solutions that must be disposed. As originally designed and installed, two separate waste streams were used at TRA; one for sanitary sewage and the second for all other waste streams. The sanitary sewage waste has always been separate from the other waste streams and is disposed into dedicated sewage

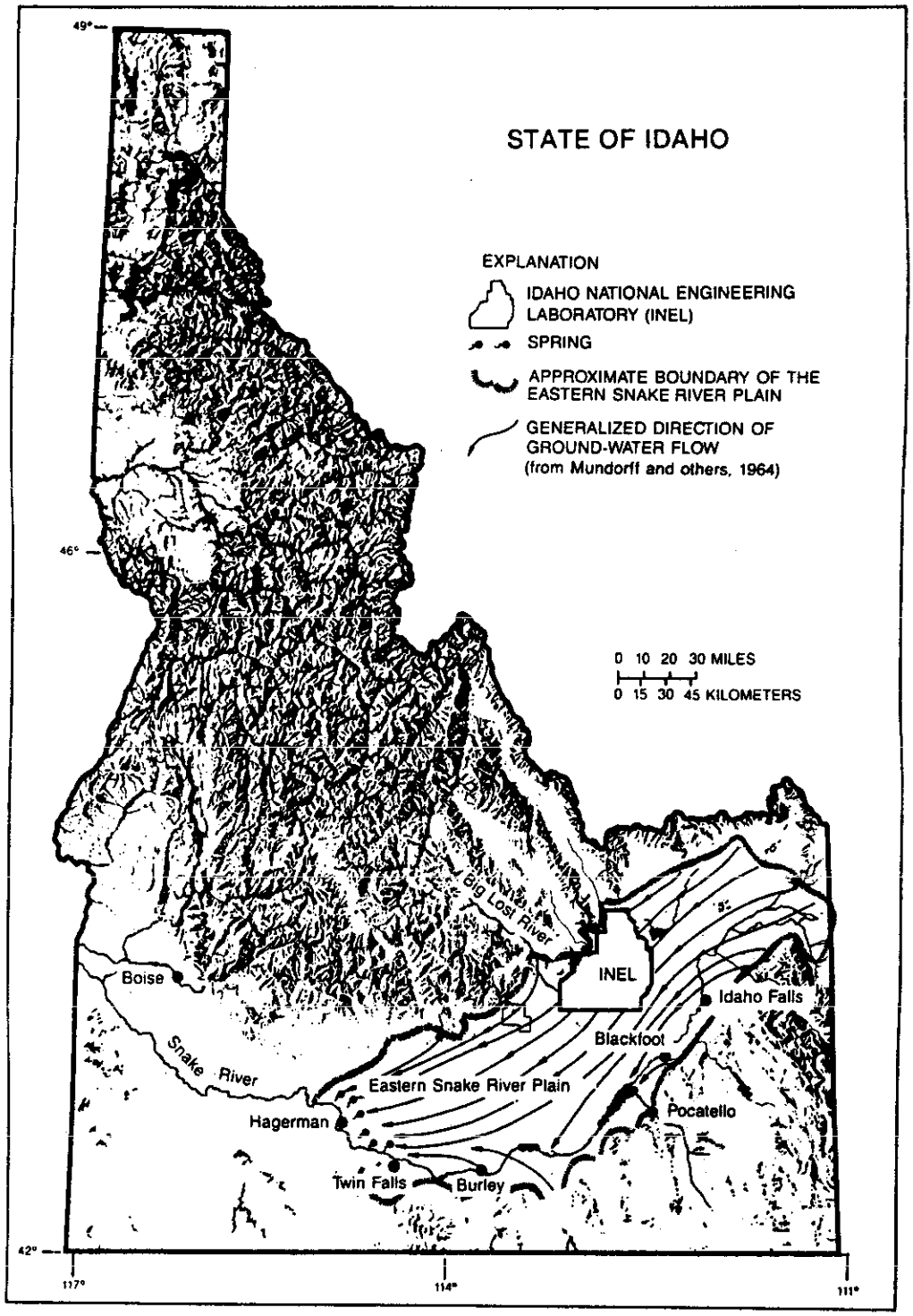
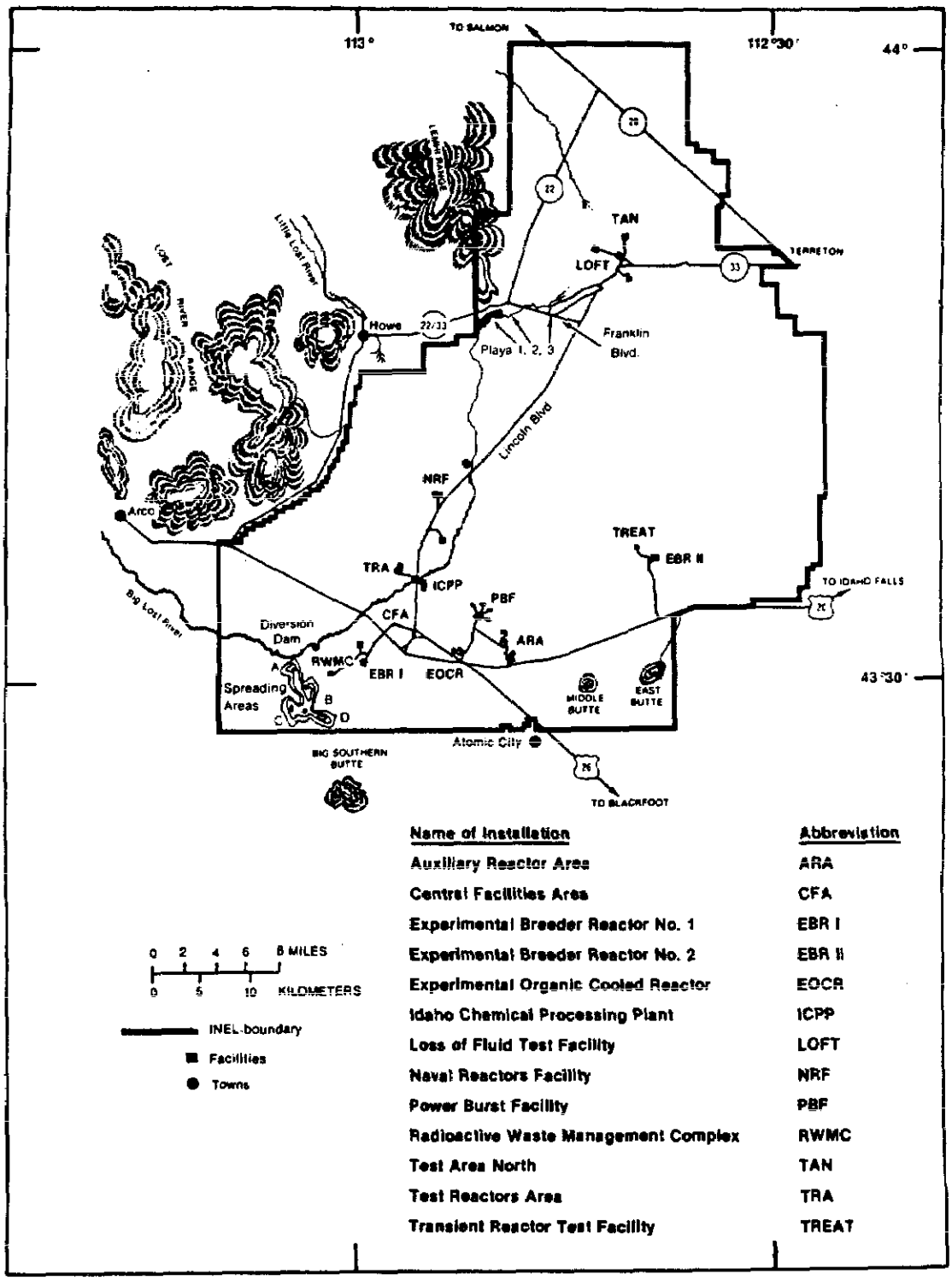


Figure 1. Relief map of Idaho showing the location of the INEL, Snake River Plain, and generalized groundwater flow lines of the Snake River Plain Aquifer.



Name of Installation	Abbreviation
Auxiliary Reactor Area	ARA
Central Facilities Area	CFA
Experimental Breeder Reactor No. 1	EBR I
Experimental Breeder Reactor No. 2	EBR II
Experimental Organic Cooled Reactor	EOCR
Idaho Chemical Processing Plant	ICPP
Loss of Fluid Test Facility	LOFT
Naval Reactors Facility	NRF
Power Burst Facility	PBF
Radioactive Waste Management Complex	RWMC
Test Area North	TAN
Test Reactors Area	TRA
Transient Reactor Test Facility	TREAT

Figure 2. Locations of INEL facilities and surface water features.

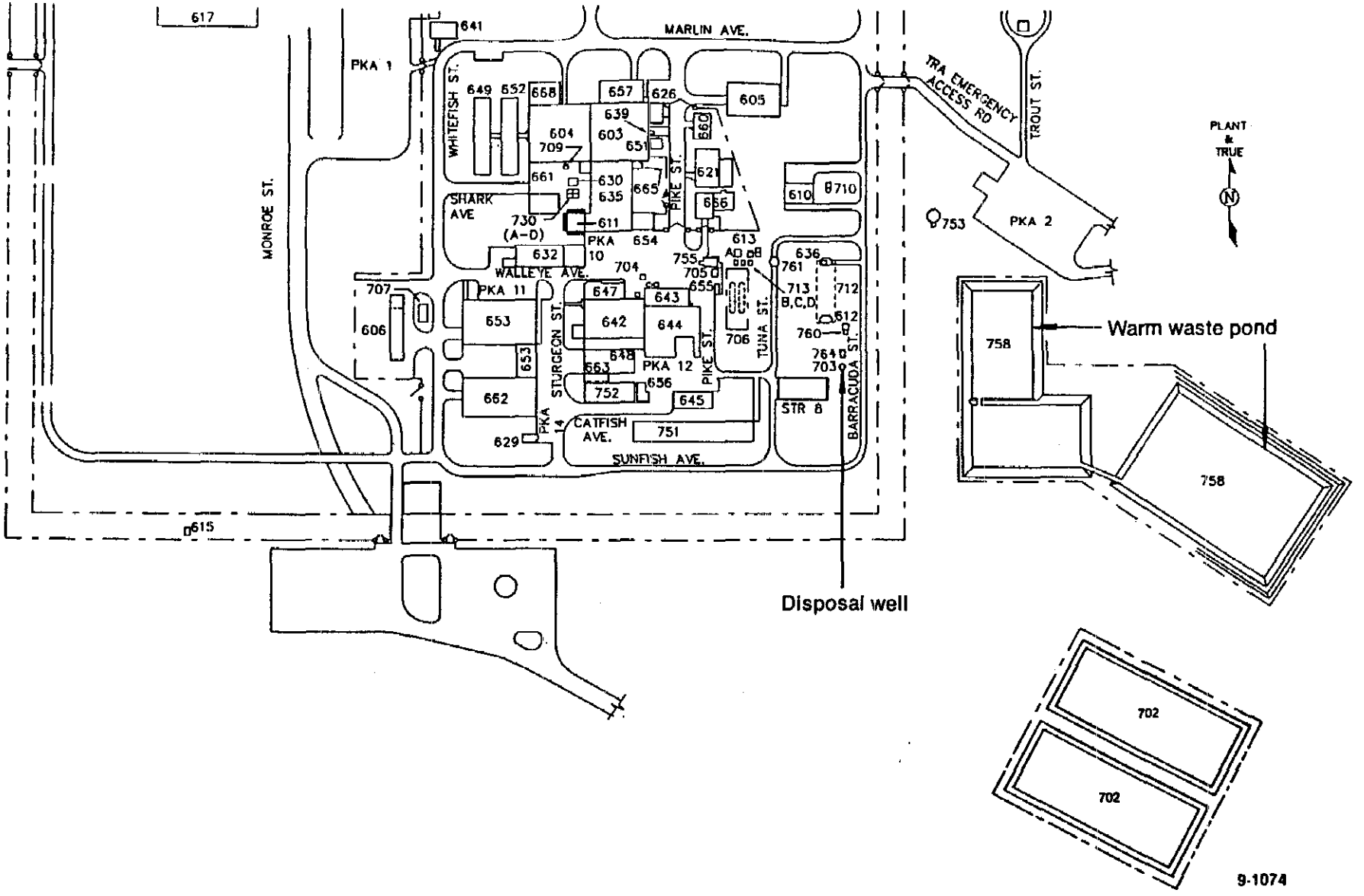


Figure 3. Map of Test Reactor Area showing the location of the Warm Waste Pond, retention basin, and Disposal Well.

lagoons. The sanitary sewage waste will not be considered further here. Over the years, additional segregation of waste streams has taken place as described below.

Originally, all non-sewage waste streams were collected in a sump pit in the southeast corner of TRA. Waste water from the sump was pumped to the Warm Waste Pond periodically when the water reached a certain level in the sump. Pumping frequently was every 5 to 8 h when all waste streams were going to the sump in 1962 and 1963 (Morris and others, 1963). Currently, the sump is pumped approximately once a day.

Radioactive waste streams pass through a retention basin prior to overflowing into the sump to provide time for short-lived radionuclides to decay. The retention basin consists of two 360,000-gal cells in parallel with baffle plates. Since the early 1970s, it has been known that the retention basin leaks, although it is not known when the leak started. The exact rate of leakage is also unknown, but exceeds 30 gpm.

From the Materials Testing Reactor-Engineering Test Reactor (MTR-ETR) Plant Drain Flow Diagram, waste streams identified as going to the retention basin or sump include the following:

- cooling tower blowdown
- drains from reactors and fuel storage canals
- wash water from vent scrubbers
- drains from laboratories
- drains from hot cells
- drains from the heat exchanger building
- drains from process water building.

Because of decreased infiltration capacity of the Warm Waste Pond, nonradioactive (cold) waste streams were diverted in the early 1960s to other disposal areas. Since 1964, the Warm Waste Pond has received only radioactive waste streams. Four disposal systems have been used at TRA for non-sanitary sewage waste streams: the Warm Waste Pond, Chemical Waste Pond, Disposal Well, and Cold Waste Pond.

Warm Waste Pond

The Warm Waste Pond consists of three cells excavated in the alluvial gravels of the Big Lost River. The first cell was excavated in 1952 and has bottom dimensions of 150 by 250 ft, 2:1 side slopes, and a depth of 15 ft. Because of decreased infiltration capacity and increased discharges, a second cell was excavated in 1957, having bottom dimensions of 125 by 230 ft, 2:1 side slopes, and a depth of 15 ft. The combined capacity of the two cells, when full, is 9.7 million gal. During the early 1960s, infiltration capacity continued to decrease due to buildup of chemical precipitates and algae on the floor of the pond. The third cell was excavated in 1964 with bottom dimensions of 250 by 400 ft, 2:1 side slopes, a depth of 6 ft, and a capacity of 6.2 million gal. None of the cells are lined.

The Warm Waste Pond and the associated collection system were designed to handle radioactive wastewater. However, from 1952 to 1962, all liquid wastes (except sanitary sewage) generated at TRA were discharged to this pond. Wastewater from the demineralization plant went to the pond until 1962, when it was rerouted to the newly built Chemical Waste Pond. Other cold waste water, including blowdown from the cooling towers, was disposed to the pond until 1964. A history of volumes of water discharged to the Disposal Well and the ponds at TRA is shown in Table 1.

Most of the water discharged to the surface ponds at TRA infiltrates into the surficial sediments. Evaporation from small lakes in Southeastern Idaho is on the order of 32 to 36 in./yr (Linsley and others, 1982). For the periods when the 1952 and 1957 cells were at least full enough to cover the bottoms of the two cells, this would amount to 1.3 to 1.5 million gal/yr. This amount of water represents less than 1% of the annual discharge to the ponds when flow exceeded 150 million gal/yr (prior to 1978), and only 3% to 8% of more recent flow volumes. Therefore, evaporation losses comprise a relatively small percent of the total discharge to the ponds.

TABLE 1. FLUID DISCHARGES TO TRA PONDS AND DISPOSAL WELL

Year	Warm Waste Pond	Chemical Waste Pond	Disposal Well	Cold Waste Pond	Sewage Treatment Pond	Total
	(Discharge in millions of gallons per year)					
1952	75	--	--	--	--	75
1953	75	--	--	--	--	75
1954	75	--	--	--	--	75
1955	97	--	--	--	--	97
1956	94	--	--	--	--	94
1957	107	--	--	--	--	107
1958	266	--	--	--	--	266
1959	232	--	--	--	--	232
1960	221	--	--	--	--	221
1961	232	--	--	--	--	232
1962	283	--	--	--	--	283
1963	202	45	--	--	--	247
1964	172	45	--	--	--	217
1965	146	45	90	--	--	281
1966	130	37	90	--	--	257
1967	181	45	90	--	--	316
1968	188	47	97	--	--	332
1969	279	45	150	--	--	474
1970	281	45	199	--	--	525
1971	191	46	136	--	--	373
1972	217	73	129	--	--	419
1973	269	31	209	--	--	509
1974	246	31	373	--	--	650
1975	220	26	343	--	--	589
1976	200	26	457	--	--	683
1977	147	22	382	--	--	551
1978	125	20	271	--	--	416
1979	74	17	263	--	--	354
1980	57	12	333	--	--	402
1981	55	9.3	244	--	--	308
1982	51	8.9	37	203	--	300
1983	26	6.7	--	238	--	271
1984	19	5.8	--	248	6.0	279
1985	20	6.0	--	222	7.2	255
1986	25	6.3	--	272	8.5	312
1987	19	5.5	--	178	6.8	209

Tritium, as tritiated water, is one of the most abundant radionuclides discharged to the Warm Waste Pond, followed by Cr-51, Co-60 Sr-90, and Cs-137. Prior to 1964, nonradioactive waste water containing chromate was discharged to the pond. The chromate was used as a corrosion inhibitor in cooling water. After November of 1964, water containing chromate was discharged to the Disposal Well.

In August of 1963, the wastewater discharge line feeding the Warm Waste Pond broke about 250 ft west of the pond (Morris and others, 1964). A perched water body developed in the surficial alluvium around the break (Figure 4). The break was repaired, and the size of the perched water zone decreased in size. Because the break occurred during 1963 when both radioactive and chromate wastes were being discharged to the pond, it is possible that alluvial sediments became contaminated with radionuclides and chromium.

Chemical Waste Pond

The Chemical Waste Pond, located 750 ft north of the Warm Waste Pond, is used to dispose of wastewater from ion exchange columns and water softeners. The pond was excavated in 1962 and first used in November of 1962. The pond has bottom dimensions of 170 by 170 ft and 1:1 side slopes. Waste water discharged to the Chemical Waste Pond contains sulfuric acid, sodium hydroxide, and sodium chloride. Significant quantities of dissolved salts are discharged into this pond; in 1987, 270 tons of sulfate and 123 tons of sodium were disposed there. The average pH of effluent to the pond in 1987 was 7.2 (Litteer, 1988). The Chemical Waste Pond, along with the Warm Waste Pond, affects perched water zones at TRA and must be considered in this discussion of the affected environment for the Warm Waste Pond.

Disposal Well

The TRA Disposal Well is located 275 ft west of the Warm Waste Pond in the southeast corner of the TRA facility. The well was drilled in 1962 and 1963 and put into service in November of 1964. Because significant

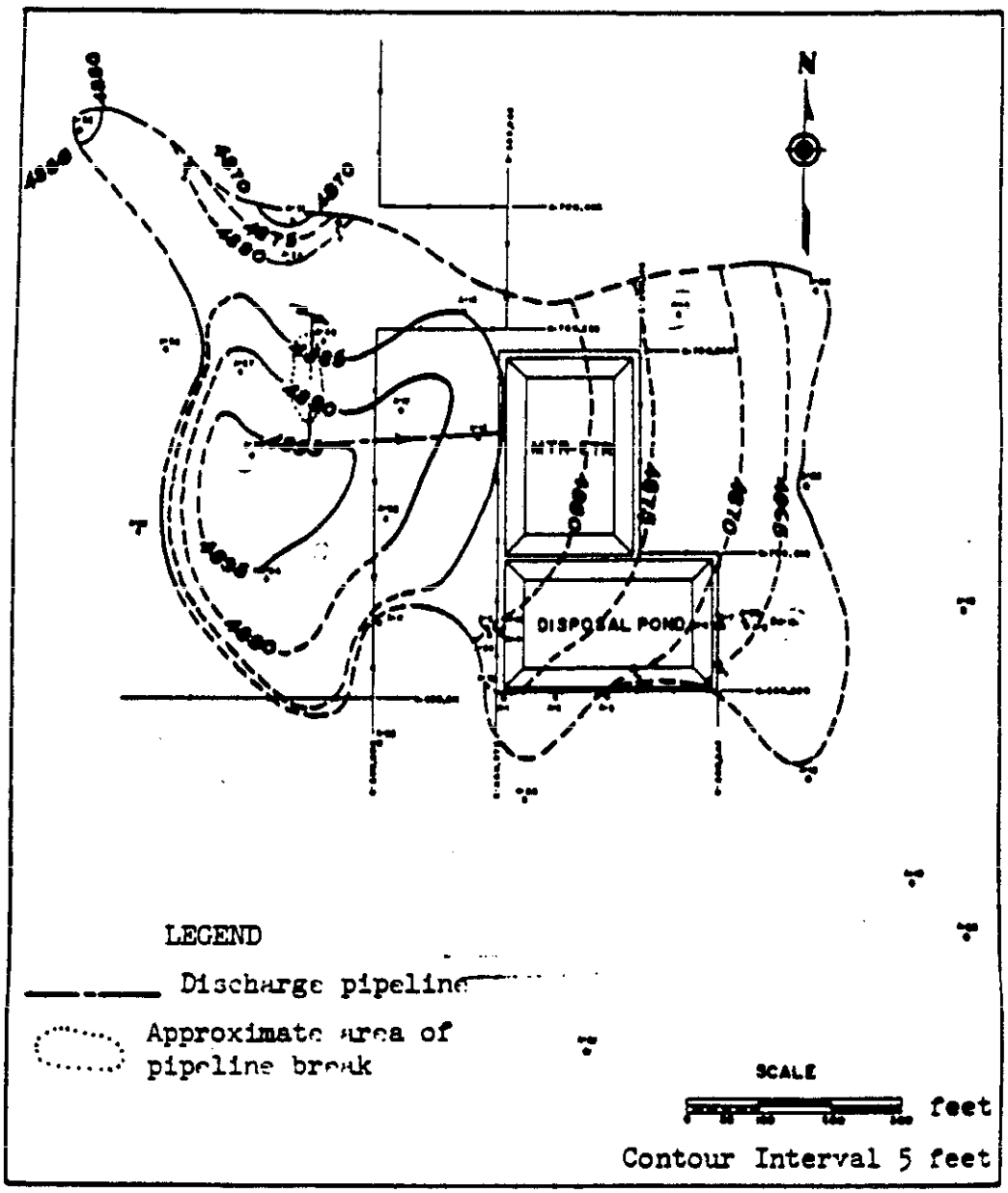


Figure 4. Distribution of the shallow perched water zone in the surficial alluvium at TRA on August 14, 1963 caused by a break in the pipeline carrying waste water to the TRA Warm Waste Pond (Morris and others, 1964).

quantities of chromates were injected into the aquifer via this well, the construction information and disposal history are of concern for the remediation of the Warm Waste Pond.

The TRA Disposal Well was drilled and cased to a depth of 1271 ft, with 1/4 in. by 6 in. slot perforations in the casing from 1182 to 1267 ft. Injection testing in early May 1965 revealed that this perforation interval resulted in insufficient capacity under gravity flow conditions (Morris and others, 1965). After accepting between 540 and 829 gpm for 44 hr, the water level rose into the surface pit 20 ft below the land surface. Between July 29 and August 3, 1964, additional perforations were added between 930 and 1070 ft. During this perforation episode, the casing was severed at a depth of 1005 ft. A 42 h injection test was run from August 3 to August 5, 1964 to evaluate the effect of the additional perforations. After 42 hours at an average disposal rate of 700 gpm, the water level rose into the surface pit, 20 ft below the land surface. A third set of perforations were made in the interval between 512 and 697 ft on August 6, 1964. Addition of the upper perforations allowed flow rates to the well of over 1000 gpm without measurable head buildup and made the well suitable for daily operation. Disposal began in November 1964.

At all perforated levels, the well intersects the Snake River Plain Aquifer, which is the regional aquifer. From geophysical logs, the rock in the upper perforation interval appears to be high porosity basalt. During the first remedial perforation activity, the casing in the well was severed, and the casing shifted in the wellbore. Since then, it has been impossible to get any geophysical tools past a depth of 1010 ft (Morris and others, 1965).

Figure 5 shows the results of a number of flow meter surveys conducted in the wellbore. Flow meter surveys were made by injecting a small quantity of radioactive tracer at a point in the wellbore and measuring the rate at which the tracer moved up or down the wellbore. The surveys illustrate the effect of the perforations on the discharge of injected fluid to the formation. During Injection Test E (Figure 5), 525 gpm of

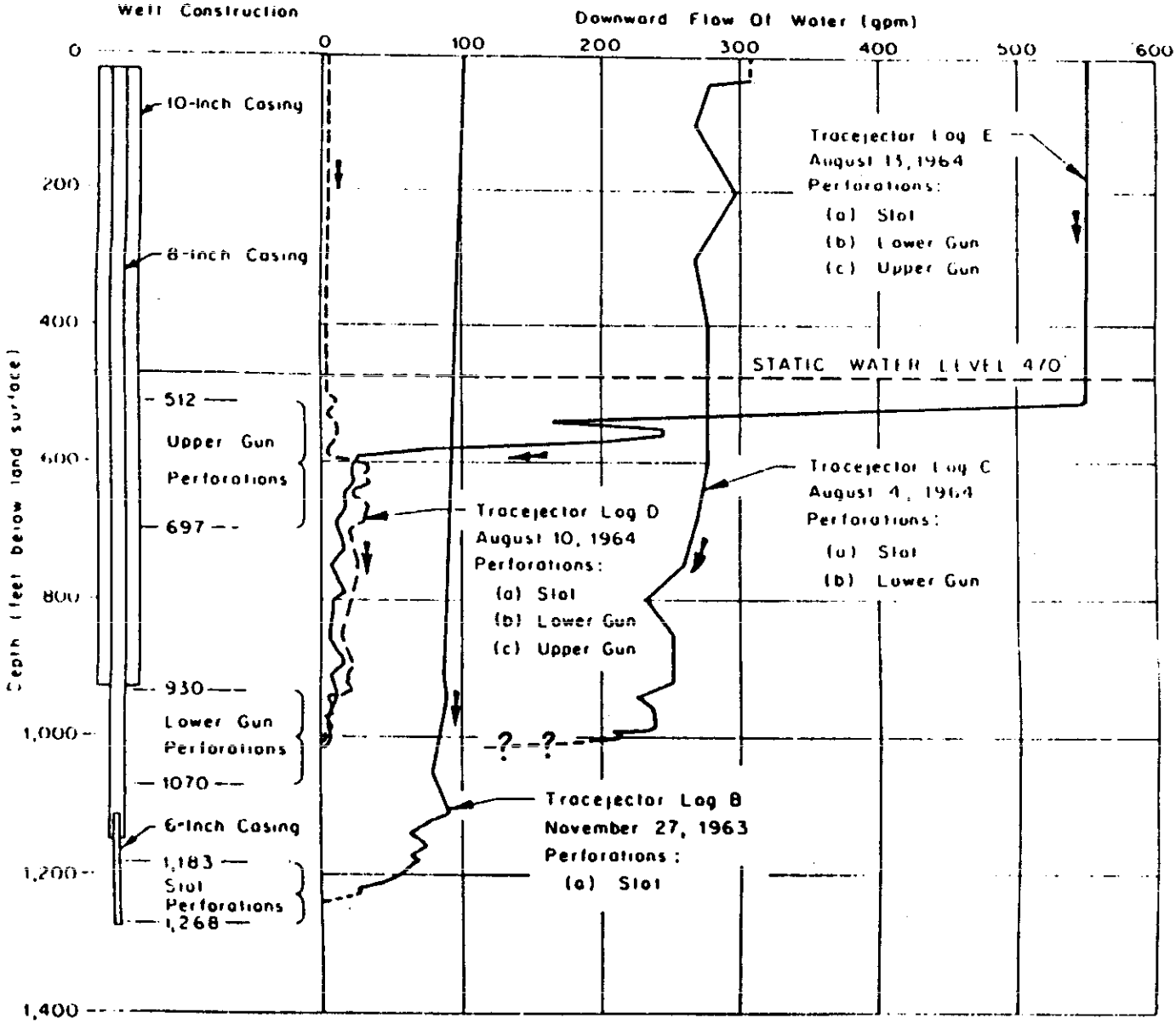


Figure 5. Graph of the perforation details of the Disposal Well and four tracejector survey logs (Morris, and others, 1965).

550 gpm (95%) injected into the well discharged over the interval 512 to 590 ft below land surface. Therefore, most of the effluent injected into the Disposal Well probably entered the formation over this interval, with relatively little of the injected fluid entering the deeper perforated intervals.

The Disposal Well was used until 1982 when it was capped and its related piping disconnected. The well is now used by the U. S. Geological Survey (USGS) to monitor water level and water quality in the Snake River Plain Aquifer. Wastewater that would have been disposed to the well was rerouted to the Cold Waste Pond.

Cold Waste Pond

In 1982, a new surface pond, the Cold Waste Pond, was constructed 350 ft south of the Warm Waste Pond to handle non-radioactive wastewater. The pond consists of two cells, each 150 ft wide and 400 ft long. The water disposed to the Cold Waste Pond is primarily cooling water from blowdown during reactor operations.

Well USGS-53

Well USGS-53 was used for injection of "chemical waste" between November 1960 and January 1962, June 1963 and August 1963, and November 1963 and September 1964 (Morris and others, 1965). Injection rates were reported to be 100 gpm. Well USGS-53 is 90 ft deep and was completed in the deep perched water zone beneath TRA. This well has not been used for waste disposal since 1964. No additional information on the types and quantities of waste could be found.

Current Status

The Warm Waste Pond continues to receive radioactive waste water from the Test Reactor Area. Plans are being developed to replace the existing pond with a new, lined pond. Remedial action alternatives for the Warm Waste Pond are being evaluated.

BACKGROUND AND SETTING

Surface Features

The INEL is located about 40 miles west of Idaho Falls, Idaho, and occupies the northwestern portion of the Eastern Snake River Plain. The INEL is bounded on the northwest by three major mountain ranges: the Lost River, Lemhi, and Bitterroot Ranges (Figure 2). The remainder of the INEL is bounded by parts of the Eastern Snake River Plain (Bowman, and others, 1984).

The land surface of the INEL is relatively flat-lying, semiarid, sagebrush desert. The predominant relief in the area is from volcanic buttes or unevenly surfaced basalt flows and/or flow vents and fissures. Elevations on the INEL range from 5200 ft in the northeast to 4750 ft in the southwest, with the average being 5000 ft (Bowman, and others, 1984). A broad topographic ridge extends from the southwest to the northeast through the INEL. This ridge effectively separates the drainage from the mountains to the northwest from that of the Snake River.

In the western and northern portions of the INEL, the Big Lost River, Little Lost River, and Birch Creek have created a flood plain consisting mainly of gravel and sand derived from mountain ranges to the northwest. The rivers drain into a series of playa lakes or sinks (Figure 2), which recharge the Snake River Plain Aquifer.

Meteorology

TRA is located in a broad, rather flat valley along the western edge of the Upper Snake River Plain in southeastern Idaho on the INEL. All air masses entering the Snake River Plain must first cross over a mountain barrier, and in doing so, precipitate a large percentage of their moisture. Therefore, rainfall on the INEL is light. The region has semidesert characteristics with hot summers and cold winters.

The normal annual precipitation at the INEL is 9.1 in. The maximum precipitation occurs during May and June and the minimum in July. During the 28-yr period of record, there have been 13 occasions when 1.0 in. or more of rain fell in a 24-hour period. The greatest rainfall in a 24-hour period was 1.73 in. in June 1954.

Snowfall at the site ranges from a low of about 11 in./yr to a high of about 41 in./yr, with an annual average of 26 in. Normal winter snowfall occurs from November through April, although occasional snowstorms have occurred in May, June, September, and October.

The relative humidity is increased by irrigation of cropland surrounding the INEL during the summertime. In the summer, humidity reaches a maximum just before sunrise and a minimum late in the afternoon; this is contingent on temperature lows and highs. The mean annual temperature is about 44°F. Temperature extremes range from -40°F in January to 100°F in July (Bowman and others, 1964).

The potential annual evaporation from saturated ground surface at the INEL is approximately 36 in., 80% of which occurs between May and October. During the warmest month (July), the potential daily evaporation rate is ~0.25 in./day. During the coldest months (December through February), evaporation is low and may be insignificant. Actual evaporation rates are much lower than potential rates because the ground surface is rarely saturated. Evaporation from the surface of shallow lakes in Southeastern Idaho is on the order of 32 to 36 in./yr (Linsley and others, 1988). Evapotranspiration by the sparse native vegetation of the Snake River Plain is estimated between 6 to 9 in./yr. Periods when the greatest quantity of precipitation water is available for infiltration (late winter to spring) coincide with periods of relatively low evapotranspiration rates (Mundorff and others, 1964).

Weather conditions in the region include temperature inversions. Winds and clouds associated with stormy weather may prevent normal nighttime inversions. Daytime inversions may occur during the winter and may also extend into spring, if a snow cover is present.

TRA lies in a belt of westerly winds that are channeled by the terrain into a prevailing southwest-to-northwest direction. During the summer months, a very sharp diurnal reversal in wind direction occurs; blowing from the southwest (upslope) is predominate during daylight hours, and northeasterly winds prevail at night.

Wind roses for meteorological stations approximately 5 miles west (PBF) and 10 miles north (NRF) are presented in Figure 6. Wind roses show the frequency in percent of occurrence of winds from direction sectors for selected speed classes and calm periods.

The average hourly windspeed reaches a minimum of about 7.2 ft/s (5 mph) in December and a maximum of 13 ft/s (9 mph) in April and May. The greatest hourly average speed on record at the INEL was 74.8 ft/s (51 mph) from the west-southwest; the highest instantaneous speed recorded was 115 ft/s (78 mph), with the wind from the west-southwest. Calm conditions prevail 10% of the time. Strong wind gusts can occur in the immediate vicinity of thunderstorms. These gusts are usually quite localized and of short duration.

Surface Water

In the area of the Warm Waste Pond, intermittently flowing waters from the Big Lost River have created a flood plain consisting primarily of sands and gravels derived from the mountain ranges to the northwest. Because of the broad topographic ridge bisecting the INEL, surface water from the valleys between the northwestern mountain ranges flows to the Lost River Sinks in the northwestern portion of the INEL. There, the water recharges the Snake River Plain Aquifer. The sinks area covers several hundred acres and consists of fluvial and lacustrine sediments (Bowman, and others, 1984).

A diversion dam on the Big Lost River at the INEL is used to regulate flow in the Big Lost River (Figure 2). Regulation is needed to minimize

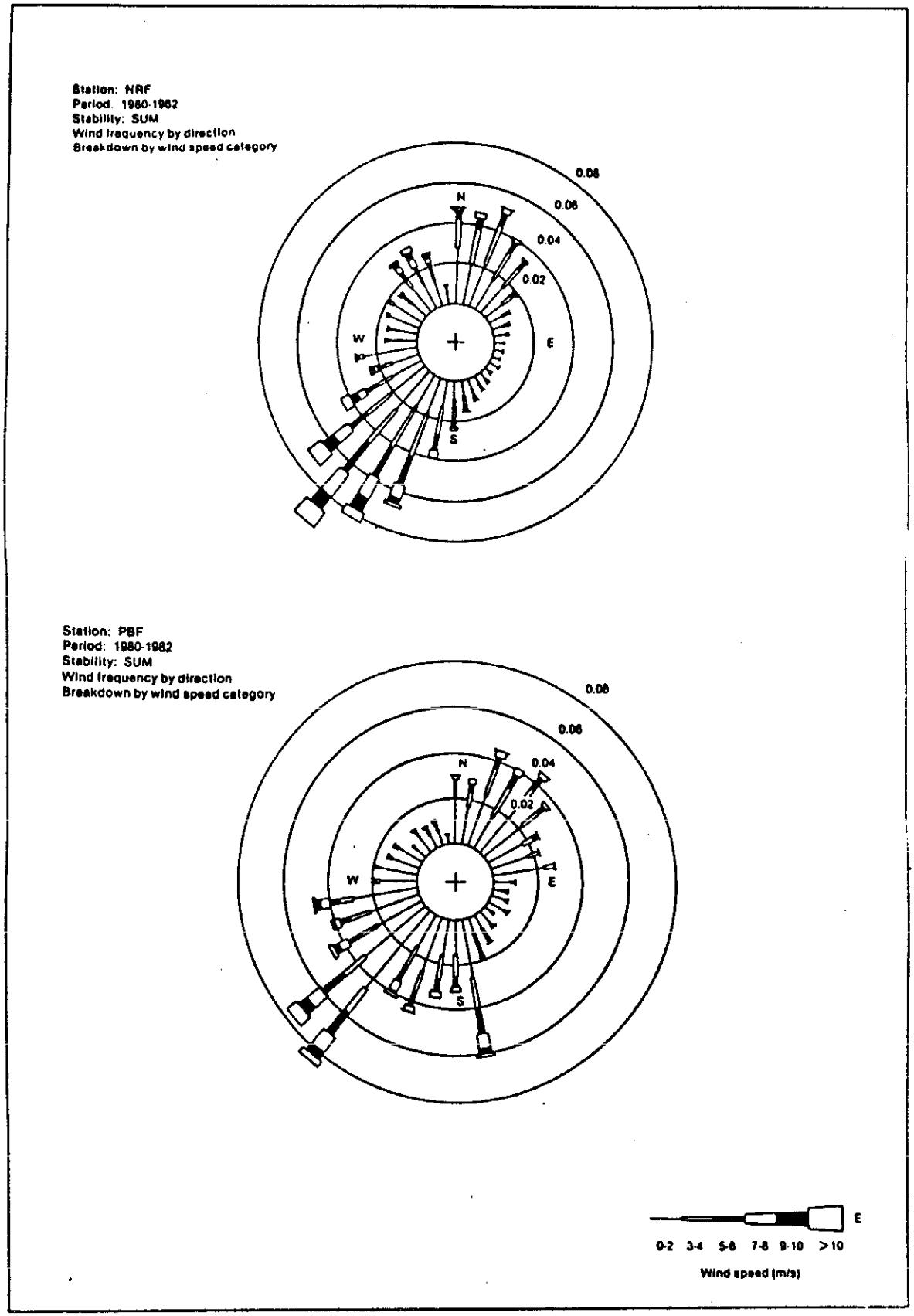


Figure 6. Annual wind roses for NRF and PBF, 1980 to 1982.

the probability of inundating several nuclear reactor facilities, a radioactive waste-disposal and storage area, and the many other support facilities that are located on the floodplain of the Big Lost River. That diversion system also protects the Warm Waste Pond. Research by the USGS (Carrigan, 1972) has defined the discharge in the Big Lost River during a 300-year flood to be 5300 cuft/s. The capacity of the flood diversion system is 9300 cuft/s (Bennett, 1986). Based on these data, it appears that the diversion system will provide protection to the Warm Waste Pond against flooding from at least a 300-yr storm. The TRA area has not been flooded since construction of the facility.

A stream gaging station is maintained by the USGS on the Big Lost River where the river runs under Lincoln Boulevard, about 6000 ft southeast of the Warm Waste Pond. Figure 7 shows the monthly discharge in acre-ft measured at the Lincoln Boulevard gaging station since 1965. Flow in the Big Lost River is highly variable, with peak flows occurring in June and July due to snowmelt. There is generally no flow in the river during winter months. Flows generally declined through the late 1960s and early 1970s, reaching a minimum in the period 1976 to 1980. For a three and a half year period from 1977 to mid 1980, there was no flow in the river at all. Flows rapidly increased during the early 1980s but again declined in the late 1980s. There was no flow in the river during calendar year 1988.

Geology

The INEL is located on the Snake River Plain, which is a physiographic depression that extends from the Idaho-Oregon border to the Yellowstone Plateau. Geophysical evidence indicates that the western portion of the Snake River Plain is a graben structure bounded on both the north and south by large normal faults. The Eastern Snake River Plain is not bounded by faults and consists of a series of rhyolitic calderas overlain by a veneer of basalts. The eastern segment is a 60-mile-wide basin extending 200 miles from near Twin Falls, Idaho, to the Island Park Caldera, north of Ashton, Idaho.

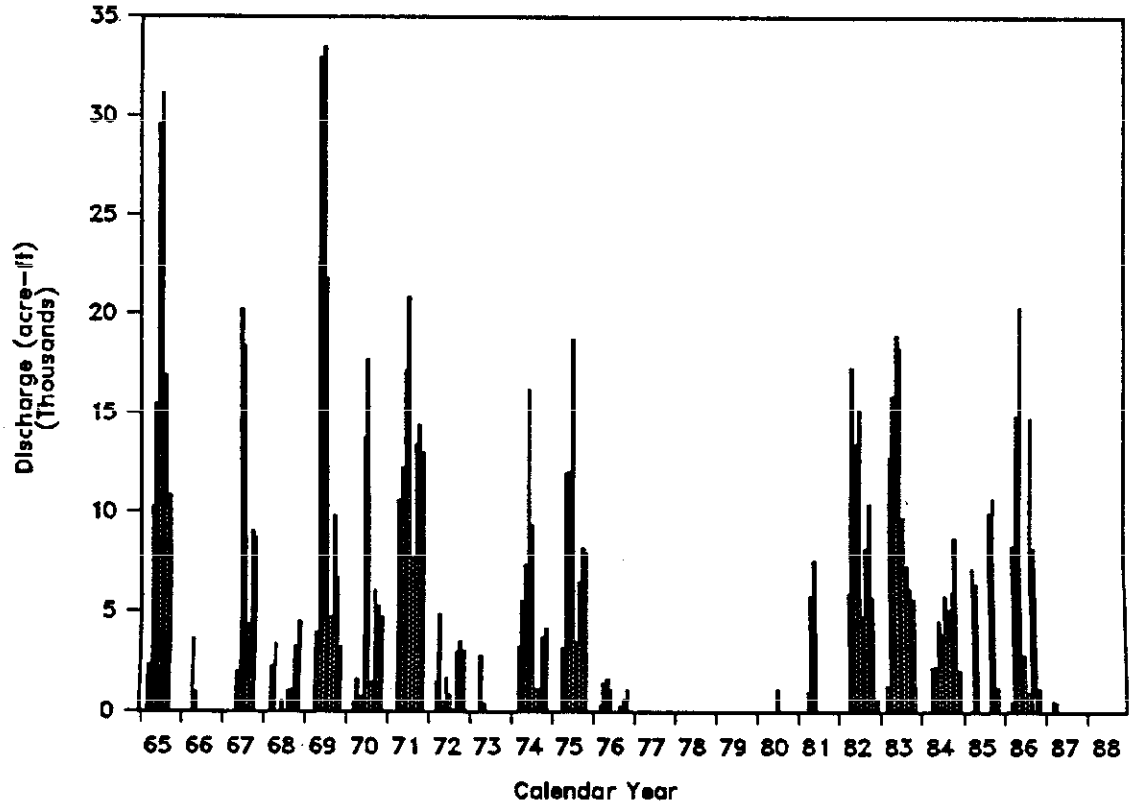


Figure 7. Monthly discharge in the Big Lost River measured at the Lincoln Boulevard gaging station.

Regional Geology

The Eastern Snake River Plain is a bimodal volcanic province that was formed in late Tertiary to Neocene time by silicic volcanic activity followed by basaltic lava flow. Silicic volcanic activity migrated from the west to the northeast (Armstrong, and others, 1975), culminating in the Yellowstone Caldera, which erupted as recently as 600,000 years ago. The volcanic material is dominated by rhyolite ash flow tuffs and lava flows (> 8200 ft in thickness), overlain by 2000 to 3000 ft of basalt and interbedded sediments.

Basalt flows erupted from four postulated rift zones that cross the Snake River Plain and trend northwest-southeast. These rifts are defined by the linear arrangement of vents, fissures, and graben (Kuntz and Dalrymple, 1979). Dating of basalt flows on the INEL gives eruption dates of 12,000 to 400,000 yr ago. The Hells Half Acre flow, immediately adjacent to the INEL site boundary, is dated at 4100 yr. The youngest basalt flows on the Snake River Plain occur along the Great Rift (Craters of the Moon National Monument) and are dated at 2100 yr old.

Much of the land surface is composed of Pleistocene and Neocene basalt flows. The western portion of the INEL is the flood plain of the Big Lost River. Alluvial sediments of Quaternary age occur in a band that extends across the site from the southwest to the northeast. The alluvial deposits grade into lacustrine deposits in the northern portion of the INEL where the Big Lost River enters a series of playa lakes (Figure 2). Paleozoic sedimentary rocks are exposed in a very small area of the INEL along the northwest boundary. A number of silicic and basalt cinder cones occur on the INEL and off the INEL near the southern boundary.

Basalt flows at the INEL characteristically occur as layers of pahoehoe lava a few feet to a few tens of feet in thickness, with an average thickness on the order of 10 ft (Nace, and others, 1956). The basalt flows are interlayered with unconsolidated sediments, cinders, and breccia. Considerable variation in texture occurs within individual basalt flows. In general, the bases of basalt flows are glassy to fine

grained and minutely vesicular. The mid-portions of the basalt flows are typically coarser grained with fewer vesicles than the top or bottom of the flow. The upper portions of flows are fine grained, highly fractured, and contain many vesicles. This pattern is the result of rapid cooling of the upper and lower surfaces, with slower cooling of the interior of the basalt flow. The massive interiors of basalt flows are generally jointed, with vertical joints in a hexagonal pattern formed during cooling. Basalt flows that were exposed at the surface often have vesicles and fractures filled with fine grained sediments and secondary calcite.

During quiescent periods between volcanic eruptions, sediments were laid down on the surface of basalt flows. These sedimentary deposits display a wide range of grain size distributions depending on the mode of deposition (aeolian, lacustrine, or fluvial), the source rock, and length of transport. A number of fairly extensive sedimentary interbeds have been identified in the stratigraphy of the INEL. Because of the very irregular topography of the basalt flows, isolated depressions are common where sedimentary material has accumulated. Thus, localized interbeds of sedimentary material occur in the stratigraphic sequence at the Warm Waste Pond.

Local Geology

The Warm Waste Pond is located on alluvial sediments deposited by the Big Lost River. This alluvium is composed of layered sands and gravels that are poorly sorted and contain very few fine-grained materials. Immediately overlying the basalt is a discontinuous layer of finer grained windblown material (Morris, and others, 1963). The underlying basalt is very dark, hard, olivine basalt that often shows distinct hexagonal jointing in excavations.

Evidence of tectonic activity has not been encountered or identified from drilling. Although the basalt flows may be locally complex and heterogeneous, the overall vertical distribution is a "layer cake" sequence of basalt and sedimentary interbeds.

Surface Alluvium. A series of characterization borings have been made around the TRA Warm Waste Ponds (Figure 8). The upper 35 to 50 ft of alluvium generally consists of well graded gravels, gravelly sands, and sands with a few fine grained materials. The upper layer is underlain in places by 0 to 5 ft of clayey sands, sandy silts, and sand-clay mixtures that directly overlie the basalt. The presence of the silt and clay layer is of particular interest because it may act as a low permeability unit beneath the pond. Furthermore, clay carried by infiltrating groundwater may have infilled fractures in the underlying basalt.

The thickness of the alluvial material at the Warm Waste Pond can be estimated from wells and auger holes drilled around TRA (Figure 9). These borings indicate between 45 and 55 ft of unconsolidated material may be present where the pond is constructed. As Figure 9 illustrates, the alluvium varies in thickness from as little as 15 ft to the west of TRA to as much as 80 ft thick south of TRA. Grain size analyses and boring logs indicate that near the surface the alluvium is coarse grained. Table 2 shows results of grain size analyses and hydraulic properties tests conducted on samples from auger hole A-10 drilled immediately adjacent to the Warm Waste Pond (Figure 8).

Basalt and Interbeds. Over the past 40 years, over 170 characterization, monitoring, and production wells have been installed on the INEL. Well logs, water levels, and water chemistry data are available in files at the INEL office of the USGS, and much of these data have been published in USGS reports. Geologic data from these wells are being used to assemble a description of the subsurface geology at TRA.

Data collected from most wells on the INEL include lithologic logs, geophysical well logs, and downhole video surveys. Geophysical well logs commonly include a caliper log, natural gamma log, neutron-epithermal neutron log, and gamma-gamma (density) log. Fluid resistivity and temperature logs are run sometimes also. Geophysical logging is performed by the USGS. Hydrogeologic units presented in this report rely heavily on the geophysical well logs. All available well construction information,

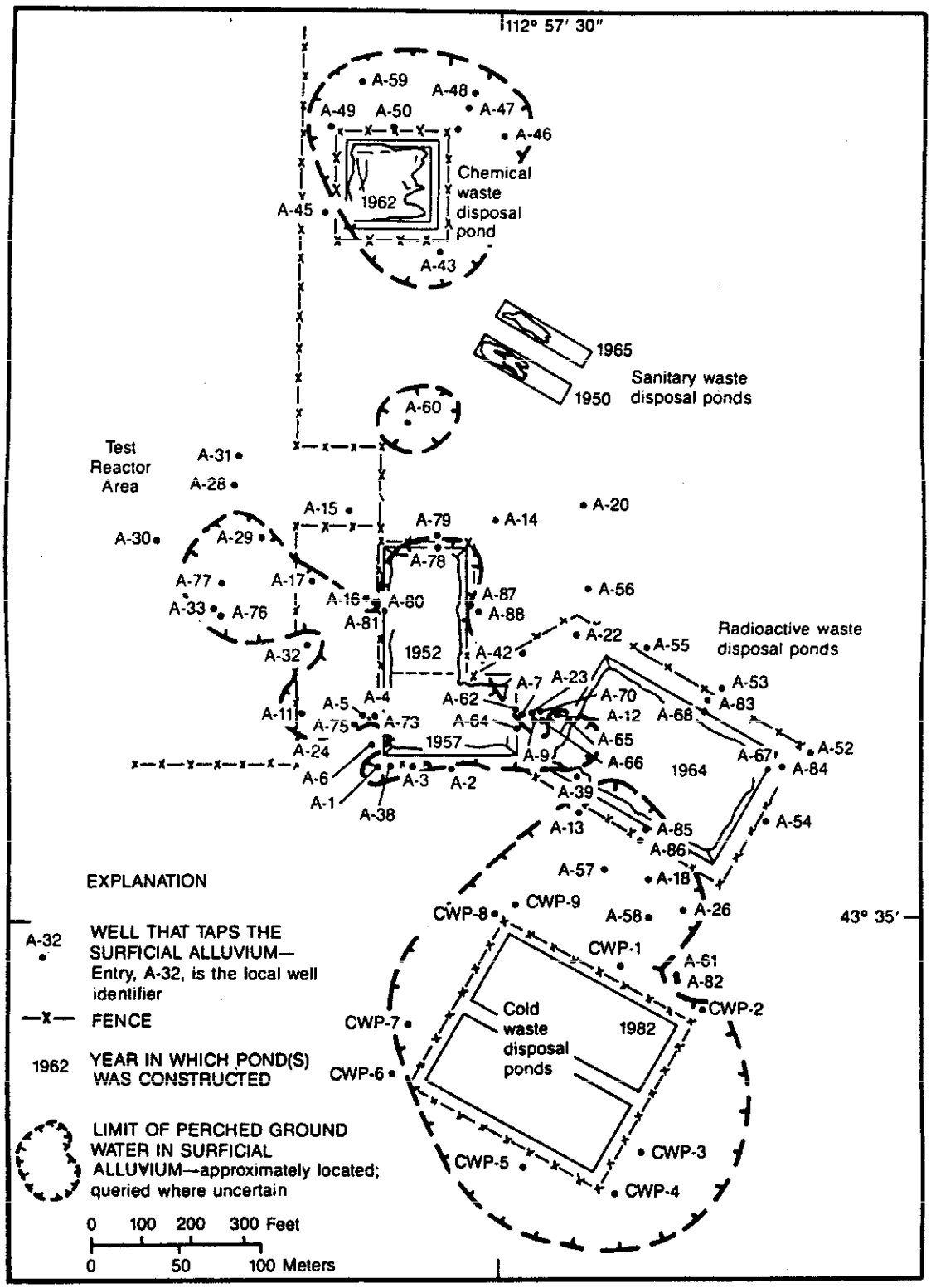


Figure 8. Disposal ponds, observation wells, and the extent of the perched groundwater zones in the alluvium near the TRA, October 1985 (Pittman and others, 1988).

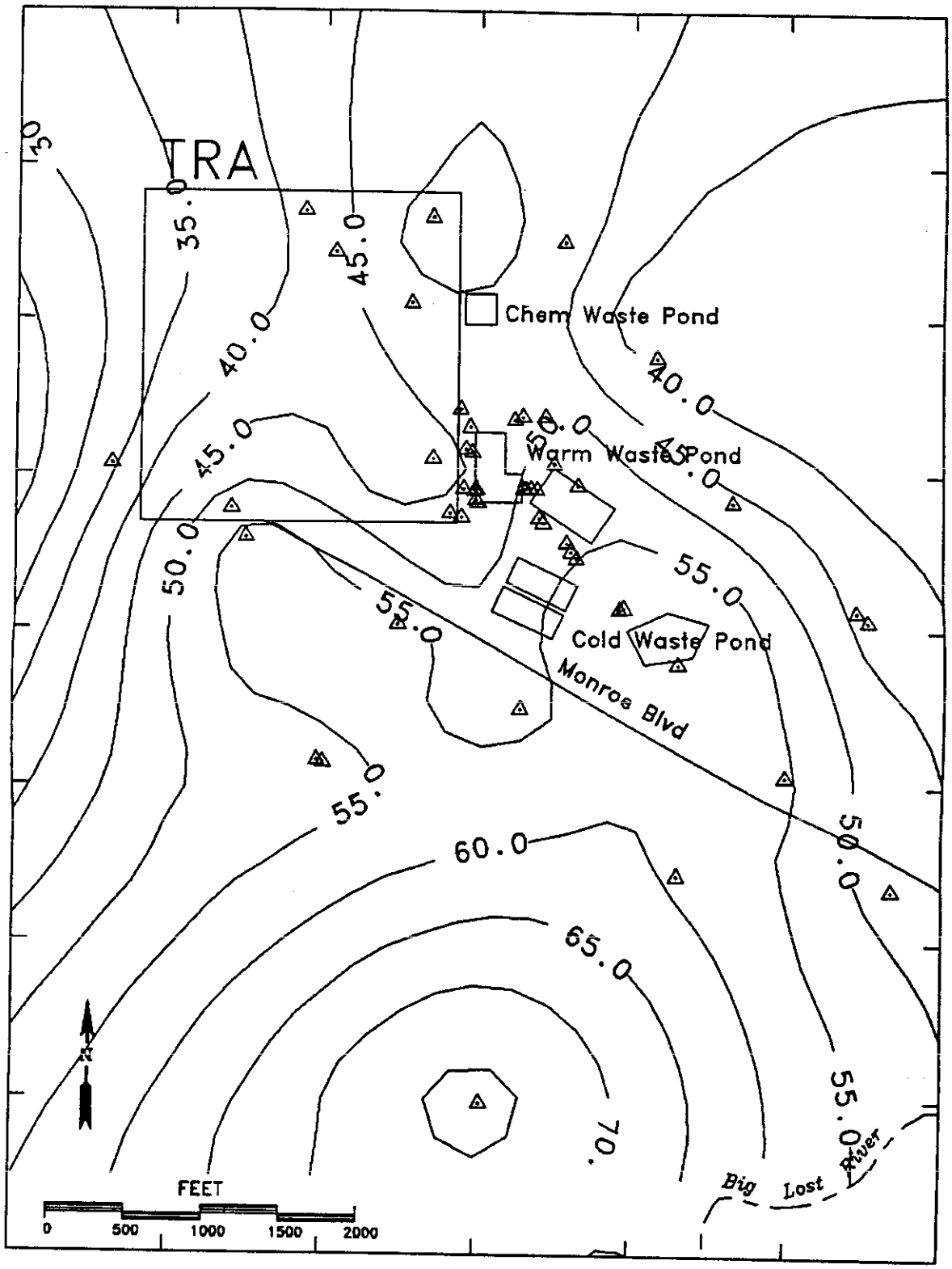


Figure 9. Thickness of surficial alluvium (ft).

TABLE 2. PHYSICAL AND HYDROLOGIC PROPERTIES OF SEDIMENTS FROM AUGER HOLE A10 (Morris et al., 1963). USGS GRAIN-SIZE CLASSIFICATION SYSTEM

Depth	Gravel	Sand	Silt	Clay	Bulk Density	Porosity	Permeability	Description
(ft)	(Percent by Weight)				(gm/cc)	(Percent)	(ft/day)	
12.5	65.8	27.4	2.8	4.0	2.00	25.9	4.4 E+00	Sandy Gravel
17.5	78.5	16.6	2.6	2.3	1.99	26.0	1.5 E+01	Sandy Gravel
20.0	70.8	20.8	4.4	4.0	2.02	24.9	1.3 E-01	Sandy Gravel
22.5	75.2	18.2	3.2	3.4	2.00	25.7	2.7 E+00	Sandy Gravel
30.0	90.4	6.4	2.0	1.2	1.67	38.1	1.1 E+03	Gravel
32.5	90.8	6.0	2.0	1.2	1.48	44.8	1.3 E+03	Gravel
35.0	87.4	8.0	2.8	1.8	1.56	42.4	1.3 E+03	Gravel
37.5	83.9	10.8	2.9	2.4	1.93	28.5	6.3 E+01	Sandy Gravel
45.0	88.3	6.7	3.0	2.0	1.58	41.3	6.3 E+02	Gravel

lithologic logs, and geophysical logs are being compiled into a computer database linked to a graphics program to display the data. Selected well logs are included as Appendix A.

Geophysical well logs, mainly natural gamma, were used to make stratigraphic interpretations. Only a preliminary identification of the four most significant hydrogeologic units at TRA has been made. These four units are the surficial alluvium, the shallowest basalt layer, the interbed that causes the perched water at TRA, and an interbed that seems to isolate well USGS-65 from the rest of the Snake River Plain Aquifer. Additional work to define the stratigraphy and hydrogeologic units at greater depths is required.

Based on the well logs, two cross sections have been constructed (Figure 10). The first cross section (Figure 11) is oriented east-west across the area and the second cross section (Figure 12) is oriented north-south. The stratigraphic units are relatively continuous in the vicinity of the Warm Waste Pond and folding and/or faulting is not apparent. Below the surface alluvial sediments is a relatively continuous layer of basalt. From the well logs, it is not possible to determine if that layer is a single flow or a sequence of flows. As is the case for most of the basalt flows on the INEL, it is not possible to distinguish between flows with any certainty. In other basalt provinces, for example the Columbia Plateau, it is possible to correlate single flows for tens and hundreds of miles based upon their geophysical signatures (Brown, 1979). That is not the case for the Snake River Basalts, and references to basalts in this report only imply a lithologic description. Stratigraphic correlation of basalt flows may be possible using techniques such as trace element geochemistry.

The uppermost basalt unit is approximately 90 ft thick. Because of the difficulty of distinguishing between cinders and fractured basalt flow tops, either in drilling returns or by geophysical logging, these intraflow features have not been correlated between wells. Such correlation has been attempted at the INEL before but has had limited success (Jones, 1961) mainly because these feature may have a limited

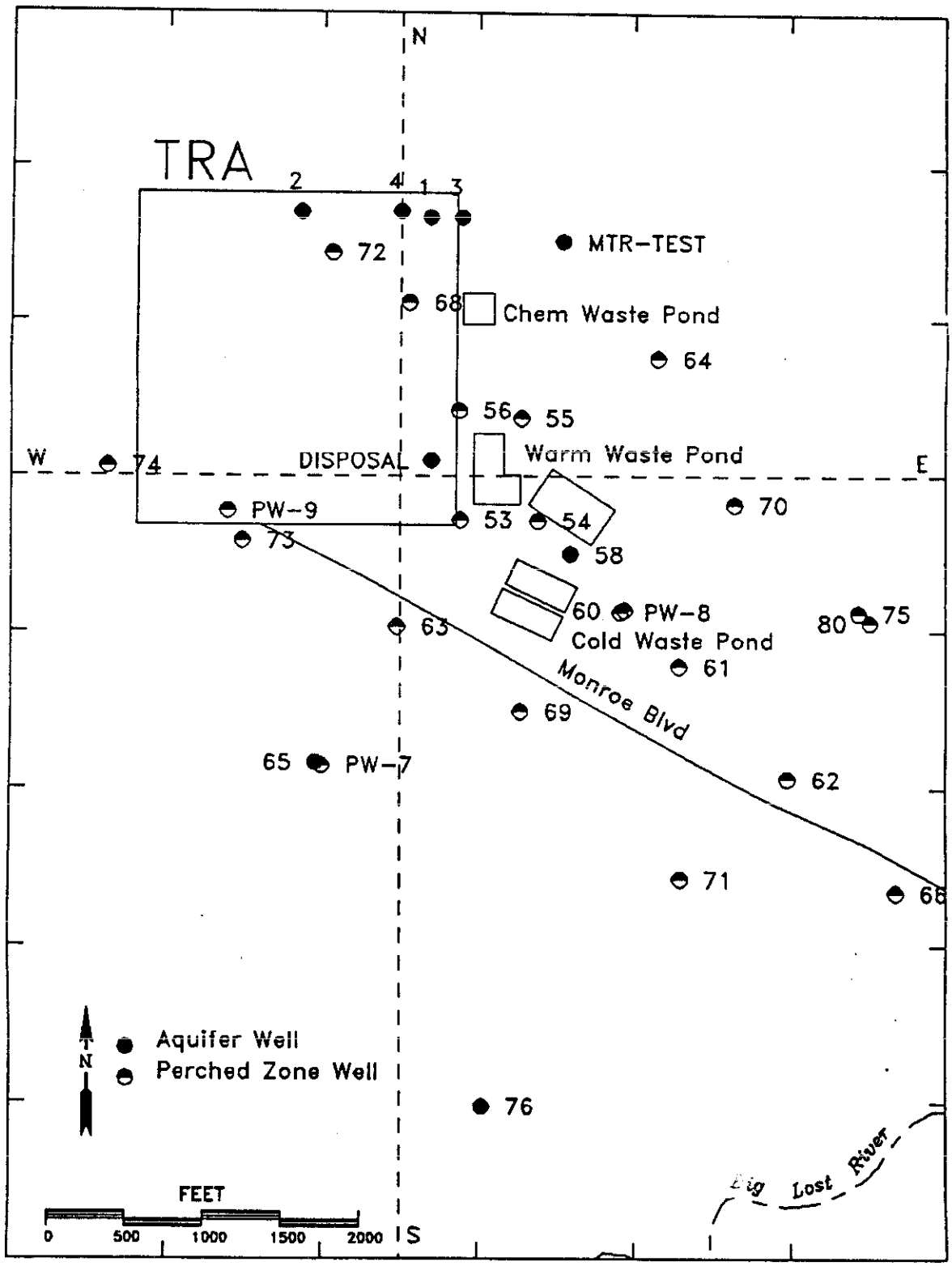


Figure 10. Locations of wells and geologic cross section lines, east-west and north-south.

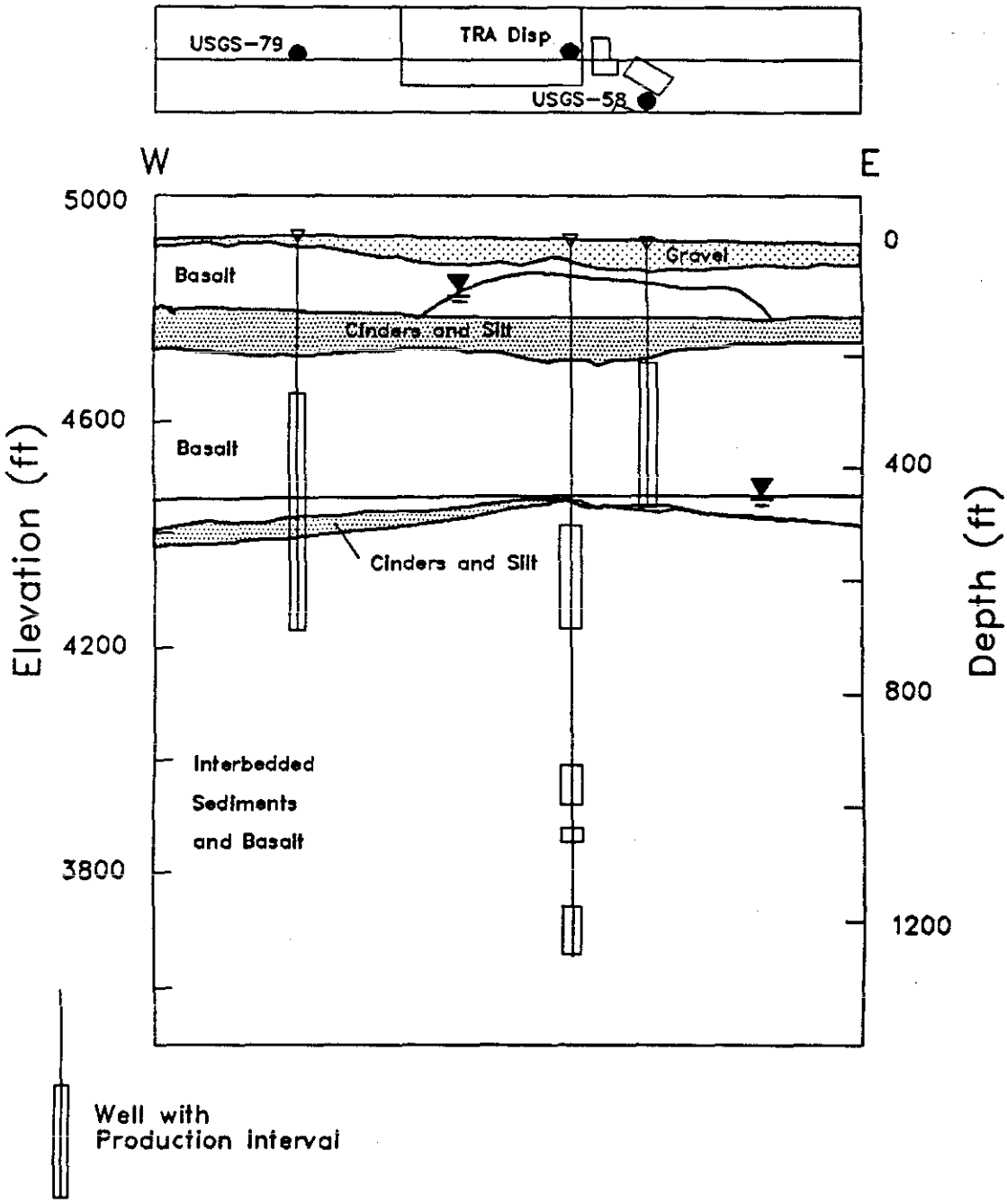


Figure 11. East-west geologic cross section through the Warm Waste Pond.

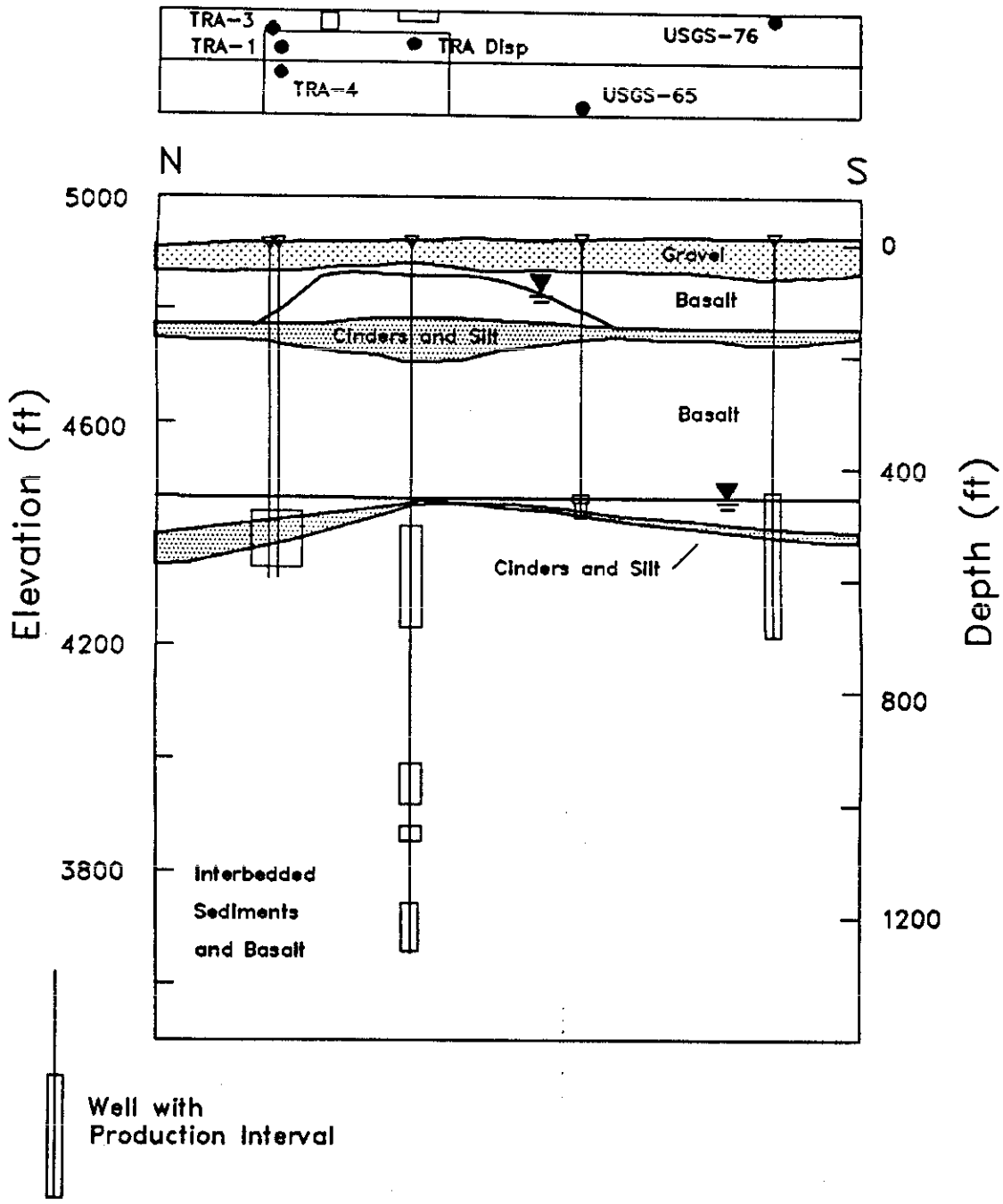


Figure 12. North-south geologic cross section through the Warm Waste Pond.

areal extent and are nearly indistinguishable between wells; that is, they generally do not posses unique characteristics, nor do they necessarily represent a significant hiatus.

Starting at a depth of about 150 ft is a 50-ft interval of silt, clay, and fractured basalt that is continuous below much of the south-central portion of the INEL. This layer has a distinctive natural gamma ray signature; it is recognized by a gamma ray count intermediate between that measured in basalt and that measured in a sedimentary interbed. It is not clear if that response is caused by a basalt flow of higher than normal natural radioactivity or if it is caused by a high clay content in fractures within the basalt. From downhole video logs, the latter appears to be the case (the basalt has a high percentage of its fractures filled with clay). This low-permeability layer is responsible for the occurrence of the deep perched aquifer zone at TRA.

Below the layer with the intermediate natural gamma ray activity (200 ft below land surface), is a sequence of interlayered basalts and sediments that extend to 2000 to 3000 ft below land surface. These lithologic features imply episodic volcanic events with intermediate periods of quiescence, which allowed deposition of sediment. At a depth of 500 ft, in well USGS-65, is a sandy, clayey, cinder zone. This bed may play a significant role in explaining why well USGS-65 has much higher chromium concentrations than any other well around TRA.

Hydrogeology

This section describes the regional and local groundwater hydrology for the TRA facilities. There are three water bearing zones of concern at TRA; the shallowest is a small perched water zone that occurs in the surficial alluvium immediately under and adjacent to the disposal ponds. Below that is a second perched water zone that has formed on a low-permeability layer in the basalt at a depth of about 150 ft below land surface. This deeper perched water zone is much larger than the shallow water zone. The perched water zones exist because of the large volumes (1 million gal/day) of water discharged into the disposal ponds at TRA. The regional aquifer, the Snake River Plain Aquifer, is the third water bearing zone and occurs at a depth of about 450 ft below the ground surface.

Snake River Plain Aquifer

The Snake River Plain Aquifer is defined as the series of water-bearing basalt flows and interlayered pyroclastic and sedimentary materials that underlie the Eastern Snake River Plain east of Bliss. The Snake River Plain Aquifer is approximately 200 miles long, 40 to 60 miles wide, and covers an area of 9600 miles^2. It extends from Hagerman on the west to Ashton and the Big Bend Ridge on the northeast (Figure 1). The aquifer's boundaries are formed by the contacts of the aquifer with less permeable rocks at the margins of the plain (Mundorff and others, 1964).

Aquifer permeability is controlled by the distribution of highly fractured basalt flow tops and interflow zones, with some additional permeability contributed by vesicles and intergranular pore spaces. The variety and degree of interconnected water bearing zones complicates the direction of groundwater movement locally throughout the aquifer (Barraclough and others, 1981). Although a single lava flow may not be a good aquifer, a series of flows may include several excellent water-bearing zones. If the sequence of lava flows beneath the Snake

River Plain is considered to constitute a single aquifer, it is one of the world's most productive (Mundorff and others, 1964).

Robertson and others, 1974, estimated that as much as 2 billion acre-ft of water may be in storage in the aquifer, of which about 500 million acre-ft are recoverable. Later estimates suggest that the aquifer contains about 400 million acre-ft of water in storage (Barraclough, 1989). The aquifer discharges about 7.1 million acre-ft of water annually to springs and rivers. Groundwater pumpage from the aquifer for irrigation totals about 1.6 million acre-ft annually (Hackett and others, 1986).

Recharge to the aquifer occurs mostly through infiltration of irrigation water (5.1 million acre-ft) and from valley underflow (1.5 million acre-ft) from the 35,000 $miles^2$ of recharge area in the surrounding mountains to the north and northeast of the plain (Hackett and others, 1986). Recharge from river seepage amounts to about 1.3 million acre-ft and direct recharge from precipitation falling on the plain is estimated to be approximately 0.8 million acre-ft/yr.

Recharge to the Snake River Plain Aquifer from within INEL boundaries is primarily in the form of infiltration from the rivers and streams draining the areas to the north, northwest, and northeast of the Snake River Plain. In most years, spring snowmelt produces surface runoff that accumulates in depressions in the basalt or in playa lakes. On the INEL, the water that is not lost to evapotranspiration recharges the aquifer because the INEL is in a closed topographic depression. Significant recharge from high runoff in the Big Lost River causes a regional rise in the water table over much of the INEL. Water levels in some wells have been documented to rise as much as 6 ft following very high flows in the Big Lost River (Pittman and others, 1988).

Flow lines for the Snake River Plain Aquifer, in the vicinity of the INEL, are depicted in Figure 13. The regional flow is to the south-southwest, although, locally, the direction of groundwater flow is affected by recharge from rivers, surface water spreading areas, and

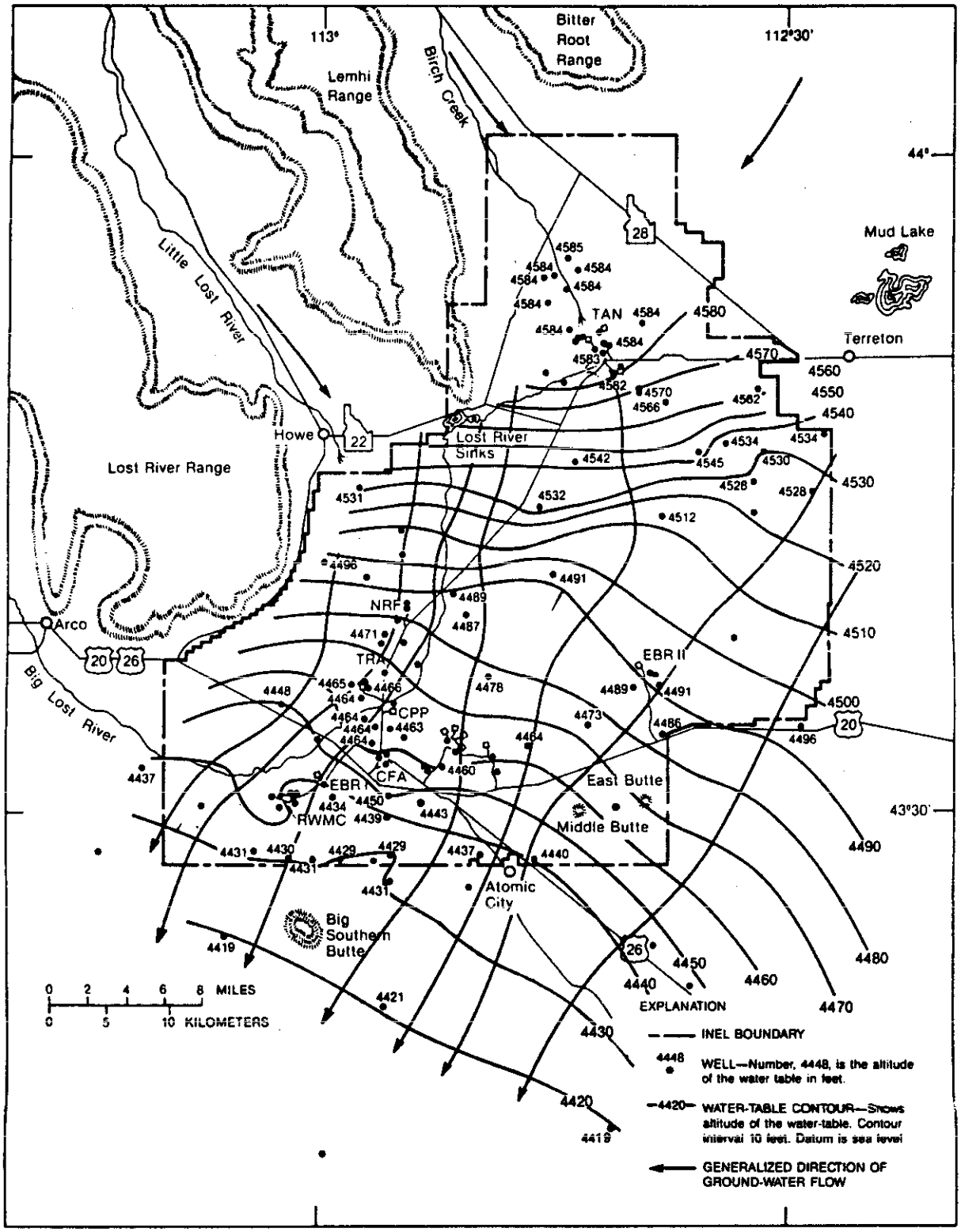


Figure 13. Altitude of the water table for the Snake River Plain Aquifer, July 1985 (Pittman and others, 1988).

inhomogeneities in the aquifer. Across the southern INEL, the average gradient of the water table is approximately 2 ft/mile (Lewis and Goldstein, 1982). Depth to water varies from about 200 ft in the northeast corner of the INEL to 1000 ft in the southeast corner.

Thickness. The thickness of the active portion of the Snake River Plain Aquifer at the INEL has been estimated to be as little as 250 ft or as much as 820 ft. Drilling information from INEL-1, a 10,365-ft-deep geothermal test well drilled about 2.5 miles north of TRA, indicates there are at least 2000 ft of basalt underlying the INEL (Prestwich and Bowman, 1980). However, not all of this thickness participates in the active flow system. Mann (1986) interpreted hydrological data from the well to indicate that the effective base of the Snake River Plain Aquifer is 840 to 1220 ft below land surface. With a known depth to water near INEL-1 of about 400 ft, Mann's estimate suggests that the active portion of the Snake River Plain Aquifer is between 440 and 820 ft thick. In developing the TRA Disposal Well, the intervals between 930 and 1070 ft and between 1183 and 1268 ft below ground surface demonstrated very low specific capacities. Those findings support a value nearer the low end of the range estimated by Mann, at least in the vicinity of TRA.

An earlier study by Robertson and others (1974) estimated the thickness of the active portion of the aquifer to be much less than 400 ft. That study, based on a mass balance of tritium disposal from INEL facilities, determined the thickness of the active portion of the aquifer to be 250 ft. That finding is based on the depth to which disposed tritium mixed with water in the aquifer and an assessment of the geology.

It is not clear which estimate is correct; however, the aquifer's thickness will vary with different areas, and there probably is not a distinct boundary between areas. With depth, the aquifer becomes less and less active in the regional groundwater system because of decreasing hydraulic conductivity. Based upon research done to date (Robertson et al., 1974; Robertson, 1974), the active portion of Snake River Plain Aquifer in the TRA area is approximately the upper 250 ft of the saturated zone.

Aquifer Parameters. Pumping tests can be performed to gather data or to determine an aquifer's suitability as a water supply. For prolific aquifers, such as the Snake River Plain Aquifer, it is essential to apply a large stress during testing. At most locations in the Snake River Plain Aquifer, a good pumping test would involve a pumping rate of approximately 1000 gpm for 72 h. To provide the best estimate of the aquifer parameters, a pumping rate of 1000 to 2000 gpm for 15 to 25 days would be required. Aquifer tests of this magnitude require large capacity pumps in large-diameter bore holes. Pumping tests have been conducted on the Snake River Plain Aquifer to determine its suitability as a water supply and for regional studies conducted by the USGS (Mundorff and others, 1964). Many of these tests were conducted by the USGS during the 1950s. Data from those older tests, which used high pumping rates, have been compiled and were used to estimate the transmissivity and storage coefficients of the aquifer near the Disposal Well.

Table 3 summarizes transmissivity and storage coefficients determined from a number of tests conducted in the vicinity of TRA. The range in transmissivity is from 120,000 to 18,000,000 gal/day/ft with a geometric mean of 2,210,000 gal/day/ft. The MTR and TRA wells are located near the Disposal Well and provide the best estimate of transmissivity for the regional aquifer in the immediate vicinity of the Disposal Well. The transmissivity of the aquifer at TRA is about 16,000,000 gal/day/ft. The transmissivity values measured at TRA are the highest measured at the INEL and probably represent a local high-transmissivity zone of about 12 $miles^2$ in area (Walton, 1958). A more reasonable estimate for regional aquifer transmissivity for the southern INEL would be a value of around 2,200,000 gal/day/ft, the geometric mean of the values given in Table 3.

Storage coefficients are relatively high (0.02 to 0.06), reflecting water table conditions in the Snake River Plain Aquifer near TRA. Estimates of the effective porosity of the aquifer range from 5 to 15% with 10% being the most accepted value (Robertson and others, 1974). This porosity estimate is a spatial average over a large volume because the

TABLE 3. SUMMARY OF AQUIFER TESTS CONDUCTED TO DETERMINE TRANSMISSIVITY AND STORAGE COEFFICIENTS OF THE SNAKE RIVER PLAIN AQUIFER NEAR TRA (Walton, 1958; Walker, 1960).

Well Number	Date	Transmissivity gal/day/ft	Storage Coefficient	Penetration Below Water Table (ft)
CFA-2	02/27/51	1.6E+05	--	209
TRA-1				144
MTR Test	07/22/57	1.4E+07	0.02	134
TRA-1				144
MTR Test	06/07/57	1.8E+07	0.06	134
TRA-3				141
SPERT	01/11/56	1.2E+05	--	196
CPP-2				153
CPP-1	11/11/51	3.3E+06	0.06	136
CPP-3				147
4N 30E 7ad	08/29/50	1.7E+06	--	367
STR-1				172
NRF-1	11/17/50	1.5E+06	--	---
STR-2	08/03/50	3.7E+06	--	163
NRF-2	02/19/57	4.3E+06	--	---
ALW	08/24/56	1.1E+06	--	180
NRF-3	03/27/57	4.8E+06	--	---
Fire Sta	11/03/58	3.1E+06	--	96
GCRE	05/20/59	2.9E+06	--	747
Geometric Mean		2.2E+06	0.042	176

aquifer is composed of massive basalt with a porosity of only a few percent and fractures and cinder zones with very high porosity.

Direction of Flow. Local anomalies in the water table of the Snake River Plain Aquifer have been recognized for many years, particularly in the vicinity of TRA and the Idaho Chemical Processing Plant (ICPP). Thirty-five years ago, professional hydrologists for the USGS set out to define a saline plume south of ICPP. Included on the team of hydrologists were C. V. Theis and W. C. Walton, two of the most respected authorities in groundwater hydrology. The researchers wrote the following about their attempt to define the plume of contamination south of ICPP:

> The detailed configuration of the water table and the direction of groundwater underflow are important considerations in the vicinity of the ICPP area and southwest of there. Regional contours on the water table indicate a general southwestward gradient of the water table. We tried to trace the course of saline liquid-waste materials in the zone of saturation by drilling test holes where interception of the waste seemed likely. Lacking direct evidence of the true direction of movement, flow directly down the apparent maximum gradient had to be assumed. Six test holes were drilled at 500-foot intervals along a 2,500-foot line normal to the direction of the apparent maximum gradient of the water table. The saline waste was not found. (Nace and others, 1956)

Eventually, the saline plume did intercept the suite of wells installed by Nace and others. Subsequent research by Barraclough and others (1981) has defined the contaminant plume south of ICPP and near CFA. Figure 14 shows the tritium concentration measured in wells of the southern INEL. This map is presented to show that the contaminant plume in the groundwater generally follows the direction of the regional water table gradient. These data suggest that waters of the Snake River Plain Aquifer move and, therefore, transport waste down the maximum gradient of the regional water table. From a hydraulic perspective, it may be possible to conceptualize the Snake River Plain Aquifer as a large porous medium, where the individual grains are tens to hundreds of feet in

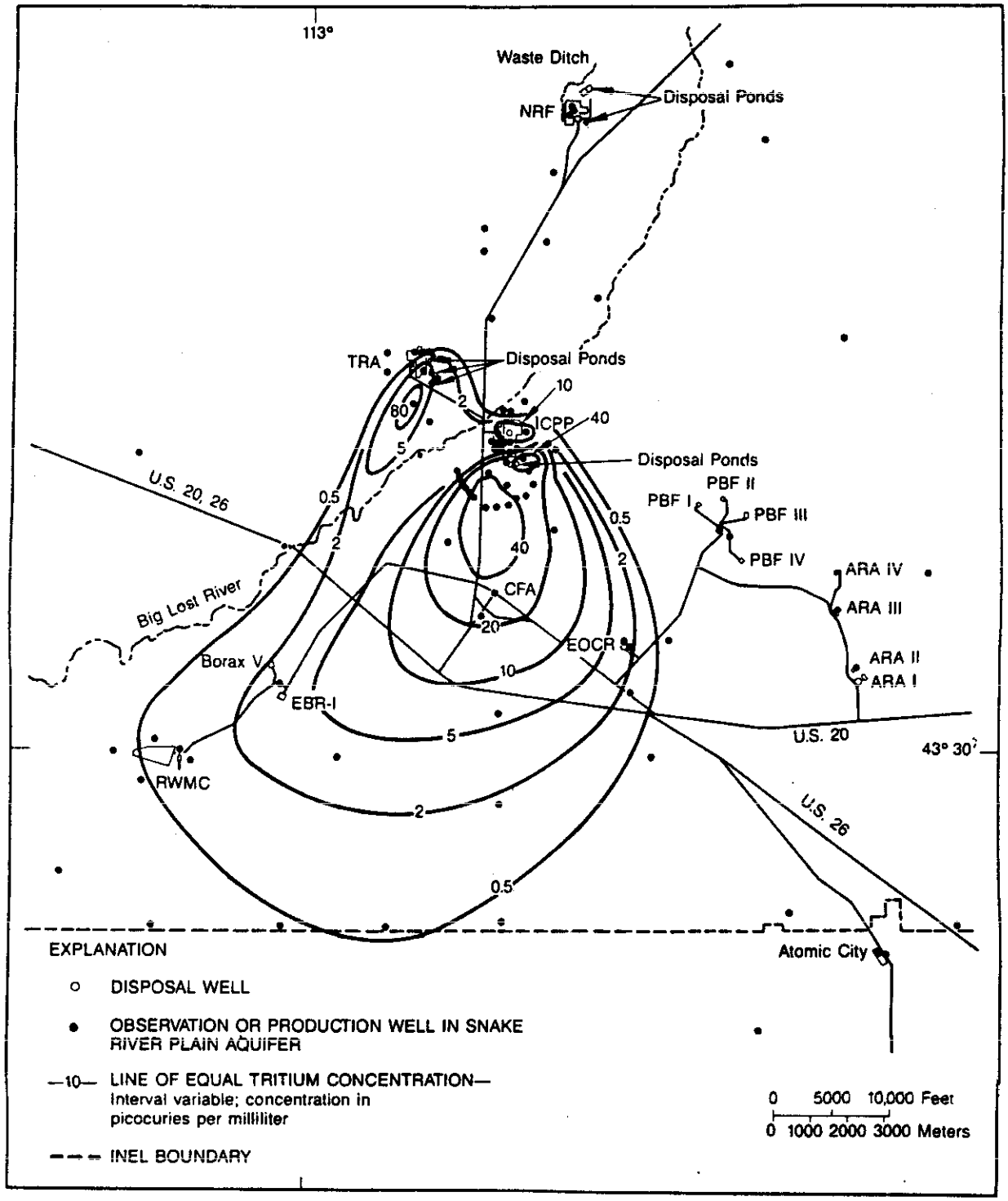


Figure 14. Distribution of waste tritium in the Snake River Plain Aquifer, ICPP-TRA vicinity, October 1985 (Pittman and others, 1988).

diameter. Flow through the aquifer would follow a sinuous path, around, through, and between the large particles, in the general direction of the regional hydraulic gradient. From a contaminant transport perspective, however, a more realistic conceptual model may be required to accurately simulate and predict the migration of contaminants.

Tracer tests of an aquifer can yield valuable information concerning flow rates and other physical characteristics. Because the standard equations for ground water flow assume a homogeneous and isotropic medium, which the Snake River Plain is not, the use of tracer information is preferred to standard analytical solutions for ground water flow. The injection of waste water into the aquifer at ICPP and TRA is, essentially, a large scale tracer test that has been monitored for more than 30 yr. Based upon the migration of contaminants from ICPP, the direction of ground water movement is in a south-southwesterly direction (Figures 13 and 14).

Rate of Flow. The rate of groundwater flow can be calculated or directly measured using tracer tests. Both methods were used to evaluate groundwater flow rates south-southwest of TRA.

The parameters used here for calculation are those that are most representative of the aquifer and have been discussed in a previous section (see **Aquifer Parameters**). The equation for groundwater velocity is as follows:

$$\nu = \frac{T}{7.48\ t\ \theta}\frac{\Delta h}{\Delta x}\ \text{ft/day} \qquad (1)$$

where

ν = groundwater velocity (ft/day)
T = transmissivity (gal/day/ft)
Δh = change in head (ft)
t = thickness (ft)
θ = effective porosity (ratio)
Δx = distance over which head change is measured (ft).

Evaluating Equation 1 gives

$$\nu = \frac{(2{,}200{,}000)\quad(2)}{(7.48\ 250)\ (.1)\ (5280)} = 4.5 \text{ ft/day.} \qquad (2)$$

Therefore, a representative velocity for flow in the Snake River Plain Aquifer south of TRA would be about 4.5 ft/day.

Direct measurements of groundwater flow rates using tracer tests provide another means of estimating groundwater flow rates near the Disposal Well. This method has been employed by monitoring the travel time of tritium peaks between wells. Groundwater flow rates ranging from 11 to 25 ft/day were determined by measuring the transit time of tritium slugs injected into the groundwater at ICPP (Barraclough et al., 1967b). Measurements were made in seven wells. Of those seven, one gave a rate of 25 ft/day, one a rate of 20 ft/day, and the other five ranged from 11 to 12.5 ft/day. The highest flow rates were measured closest to the injection well where flow was occurring under higher hydraulic gradients induced by the injection well. The longest distance over which velocity was measured was 10,400 ft.

In addition to horizontal flow, a possibility exists for vertical flow within the aquifer. A few measurements have been made on vertical hydraulic gradients at the INEL. The evidence from INEL-1, the geothermal exploration well drilled north of TRA, seems to indicate that below a depth of 1200 or 1500 ft, the gradient is upwards (Mann, 1986). Water level measurements made at various times during drilling indicate that the hydraulic head increases with depth (Table 4). There is a >100 ft higher potential at a depth of 4200 ft below land surface than at the water table, 395 ft below land surface.

After the final perforation of the TRA Disposal Well, a tracejector survey was run in the wellbore when only about 2 gpm were being injected into the well (Log D, Figure 5). About 25 gpm of formation water entered the wellbore at a depth of 590 ft. This water moved down the wellbore and discharged through the perforations between depths of 935 and 1005 ft (Morris and others, 1965). This indicates that the head is greater at a

TABLE 4. CHANGES IN HYDRAULIC PROPERTIES WITH DEPTH IN WELL INEL-1 AND THE INEL-1 WATER SUPPLY WELL (Mann, 1986).

Open hole Interval (ft below surface)	Depth to water (ft below surface)	Permeability (ft/day)
395 - 595	395	1200
1511 - 2206	330	0.03
3559 - 4879	290	0.006
4210 - 10365	280	0.002

depth of 590 ft than at a depth of 1000 ft. At the CFA landfills, two wells completed at different depths show about 2 ft of head difference. Well LF2-8 is complete over the interval 481 to 497 ft below land surface. Well LF2-10 is open to a fracture zone at about 700 ft below land surface. The water level in LF2-8 is at 4456.62 ft above sea level, while the water level in LF2-10 is at 4454.53 ft above sea level (Wood and others, 1989). In the CFA area, there is also a downward gradient of the water table to a depth of about 700 ft.

Based on calculations and direct measurements, the best estimate of the lateral groundwater flow rate for the aquifer is around 11 ft/day near ICPP and TRA. For the southern INEL in general, a flow rate of 4.5 ft/day is more realistic. At TRA, the direction of groundwater flow is to the southwest. Vertical gradients have been measured in the aquifer that indicate a minimum hydraulic potential at a depth of around 1000 ft below land surface. Because there are no measurements of vertical hydraulic conductivity, the quantities of flow associated with this head distribution cannot be calculated.

Unsaturated Zone and Perched Water Tables

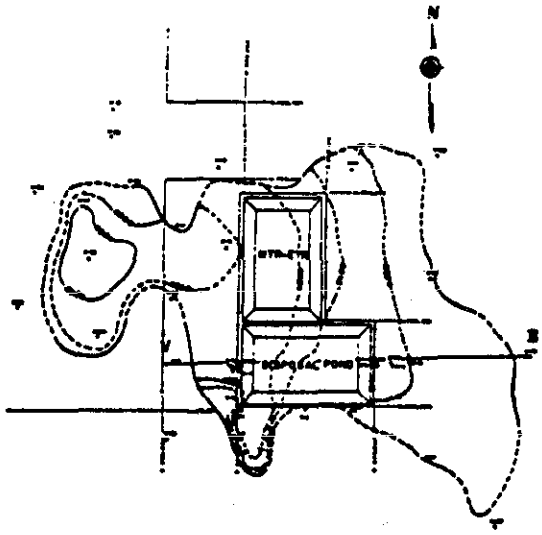
The unsaturated zone at the INEL ranges from 200 to 1000 ft thick. This very thick unsaturated zone is a complex sequence of basalt flows, breccia zones, and sedimentary interbeds. Two computer simulation studies have been conducted that provide some insight into the migration of

contaminants in the vadose zone. The USGS has studied the movement of water in the unsaturated zone beneath the TRA Warm Waste Pond (Morris and others, 1963; Robertson, 1977). Thomas and others (1986) have modeled the release of radionuclides under natural recharge conditions at ICPP.

Lateral and Vertical Extent. There are two perched water zones at TRA; a shallow one in the surficial sediments immediately beneath the disposal ponds, and a deeper one in the underlying basalts. The shallow perched zone forms on the interface between the surficial sediments and the underlying basalts. This interface is commonly marked by finer grained sediments that inhibit downward migration and may clog the openings in the underlying basalt. The deeper perched water zone forms on a low-permeability layer at a depth of about 150 ft. This layer, variously described as "cinders and clay", "basalt and silt", or "clay and basalt" in drillers logs, is identified by a distinctive peaks in the natural gamma log and can be traced throughout most of the southern INEL.

In 1962, shallow auger holes were drilled around the disposal ponds at TRA through the surficial alluvium to the basalt interface. The wells were completed with PVC or aluminum casing to serve as piezometers. Figure 8 shows the distribution of auger holes drilled in 1962 and later years around the disposal ponds at TRA and completed in the surficial alluvium, and the configuration of the perched water zone in 1985. Figure 15 shows the configuration of the shallow perched water zone in the years 1962 and 1978. The saturated region remains immediately below and adjacent to the ponds, although the shape has changed with the addition of the 1964 cell and the Cold Waste Pond. The saturation extends to the west of the Warm Waste Pond to where the sump and retention basin are located. Water disposed of to the Warm Waste Pond is held in the sump and retention basin for short time periods. The retention basin leaks, allowing water containing radioactive wastes to infiltrate the alluvium. Because this lobe was present as early as 1962, it is possible that sediments near the retention basin were contaminated with chromium, which was used as a corrosion inhibitor at the facility until 1972.

1962



1978

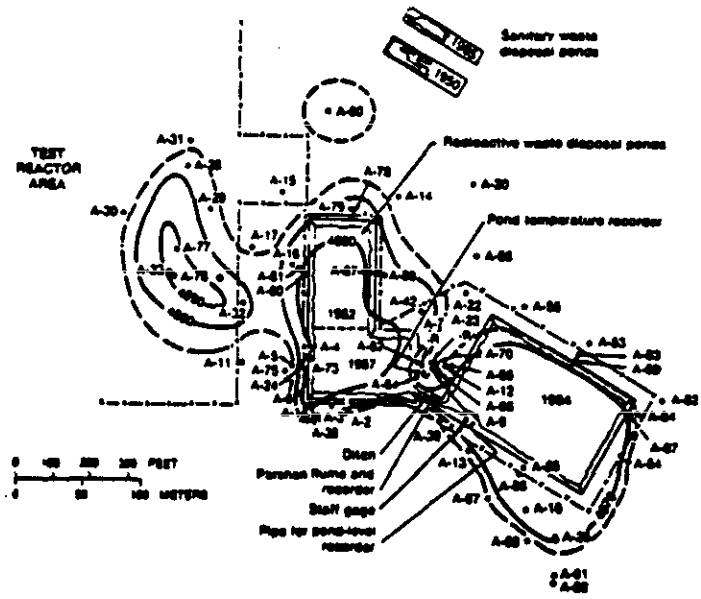


Figure 15. Configuration of the shallow perched water zone in the alluvium in 1962 (Morris and others, 1963) and in 1978 (Barraclough and others, 1981)

The deep perched water zone is much larger in areal extent than the shallow perched water zone. The size of the deep perched water zone has fluctuated over the years in response to the volume of water discharged into the surface ponds. The size of the deep perched water zone decreased when the Disposal Well was in use and all cold waste water was discharged directly to the aquifer. It reached a minimum size in about 1981. The zone has grown in response to the change from discharge to the Disposal Well to the Cold Waste Pond. Figure 16 shows the configuration of the deep perched water zone in 1978, 1981, and 1985. The configuration of the deep perched water zone in April 1988 is shown in Figure 17. Flow in the deep perched water zone is dominated by infiltration from the Cold Waste Pond (which receives 85% of water disposed into ponds). Water from the Warm Waste Pond flows primarily to the west, as substantiated by the unique chemical and radioisotope signature of water from the Warm Waste Pond in the westerly flow.

Perched Water Table Parameters. A computer simulation study was conducted by the USGS (Robertson, 1977) to determine long-term effects of waste disposal in seepage ponds at the INEL. The study involved characterizing the unsaturated zone, simulating flow and solute transport using a numerical model, and validating the model with measured water levels and solute concentrations. Based on the fits obtained between the model and the field data, parameters used in the model are reasonable estimates of conditions in the unsaturated zone at the INEL (Table 5).

In Robertson's study, vertical water velocities were calculated for the surficial sediments and for the deep basalt layers. The range in velocity for the deep basalts is dependent on the location relative to the thickness of the perching layer. Robertson (1977) calculated a flow rate of about 2 ft/day in the saturated sediments below the waste ponds. This is consistent with observations of the movement of radionuclides from the ponds. At a flow rate of 2 ft/day, it would require 225 days for water to reach the aquifer from the surface.

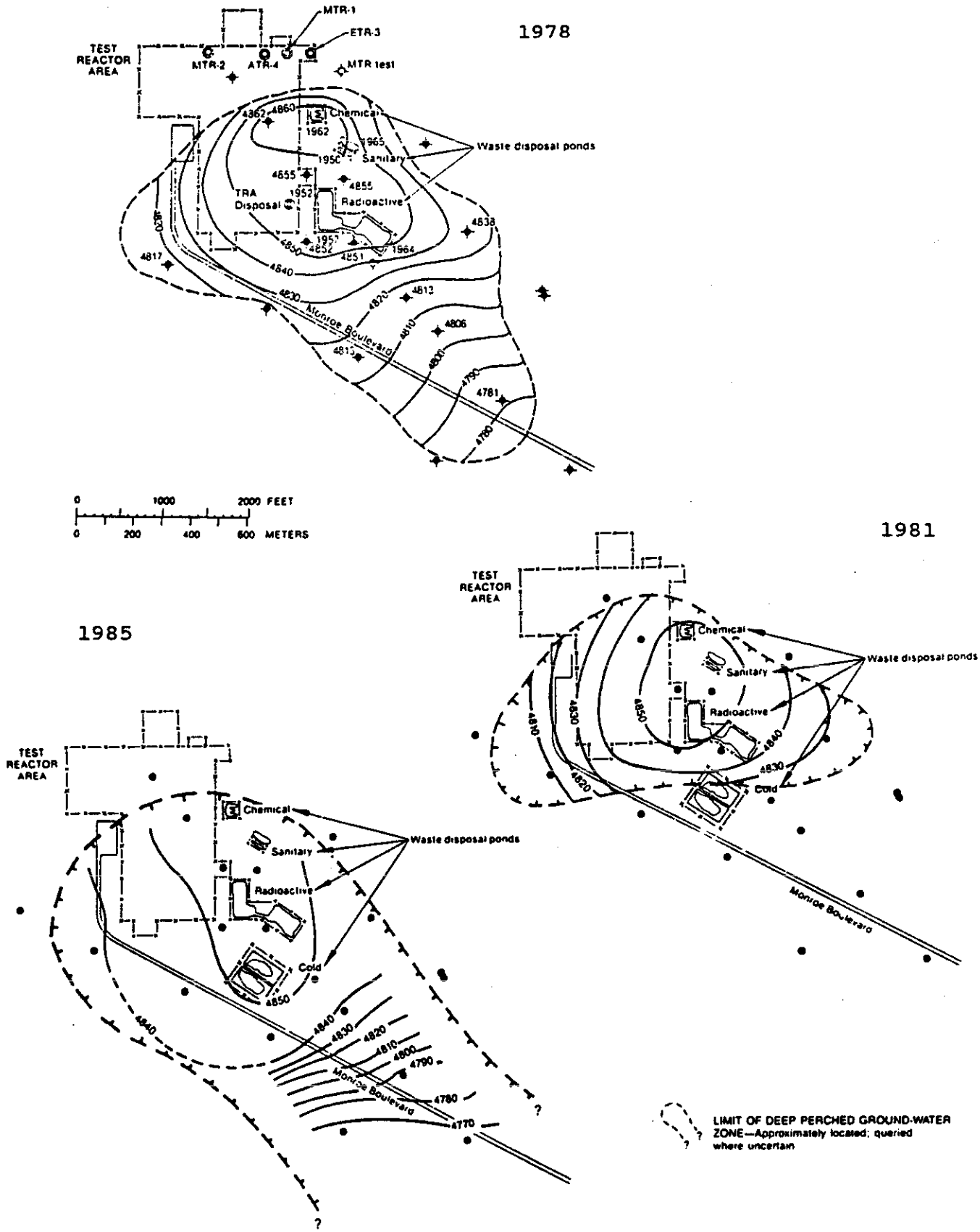


Figure 16. Configuration of the deep perched water zone in the basalt for 1978, 1981, and 1985 (Lewis and Jensen, 1984; Pittman and others, 1988).

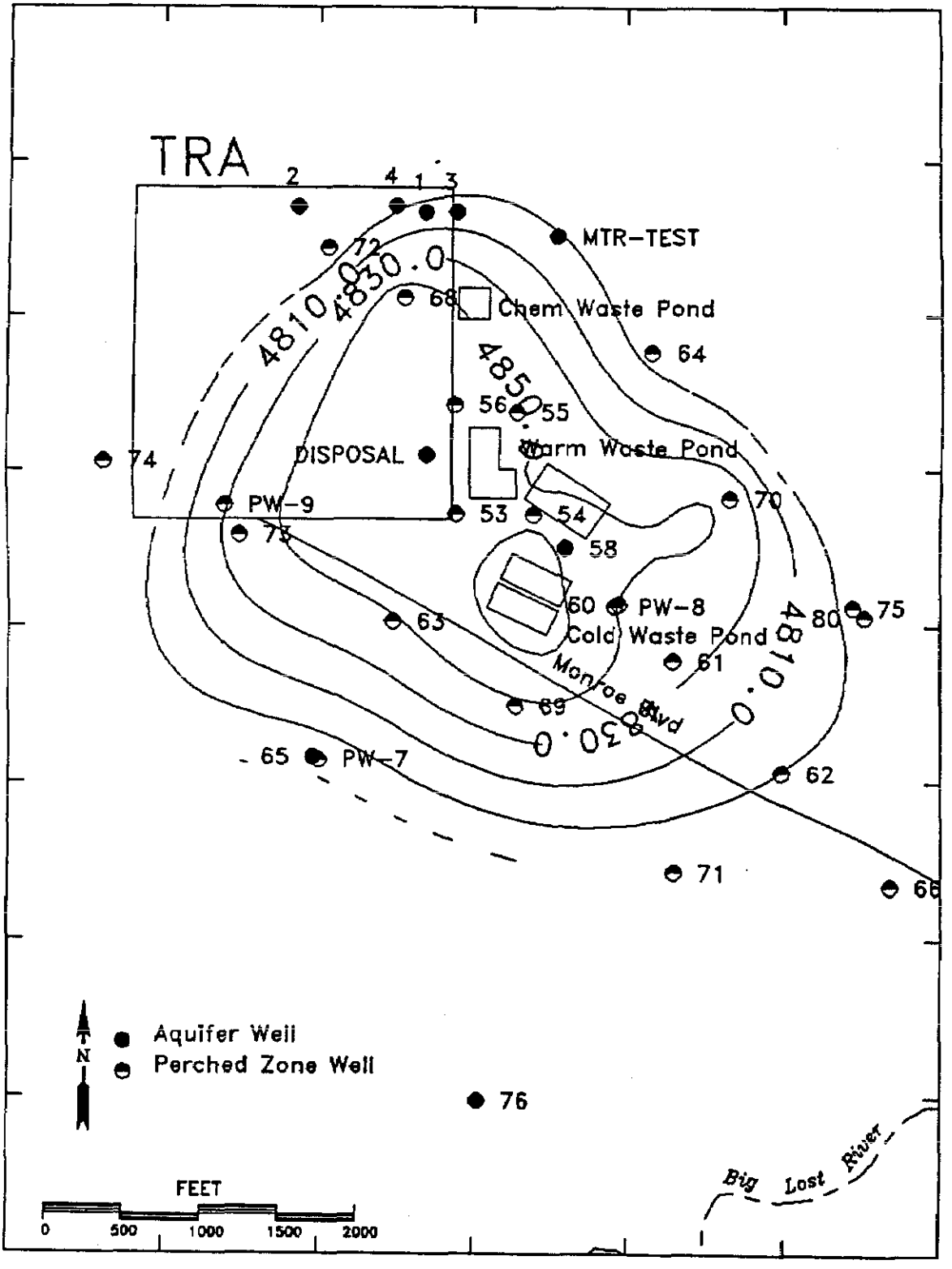


Figure 17. Configuration of the deep perched water zone at TRA in April 1988.

TABLE 5. HYDRAULIC AND PHYSICAL PARAMETERS OF THE UNSATURATED ZONE AT TRA (Robertson, 1977)

Layer	Permeability (ft/day)	Thickness (ft)	Dispersivity (ft)	Porosity (%)	Velocity[a] (ft/day)
Surface Sed.	K_v=1.0	50	α_l=10	30	2
Shallow Basalt	K_h=7	100	α_l=150 α_t=75	10	
Sed. Interbed	K_v=0.02	60	α_l=10	30	
Deep Basalt	K_v=10	240	α_l=10	10	2-6

a. Vertical velocity only.
K_v = vertical permeability
K_h = horizontal permeability
α_l = longitudinal dispersivity
α_t = transverse dispersivity

A simulation study was conducted to evaluate the migration of radionuclides from waste storage facilities at ICPP, 1.7 miles southeast of the Warm Waste Pond (Thomas and others, 1986). The unsaturated zone at ICPP is geologically similar to the unsaturated zone below TRA. The sediments and basalts simulated at ICPP were assumed to be unsaturated, which may approximate subsurface conditions after closure of the TRA pond. One of the scenarios considered by Thomas and others was the gradual leaching of radionuclides by precipitation and no retardation by soils. The authors considered 0.85 in. of infiltration/yr (about 10% of precipitation) to be an accurate estimate based on the high evapotranspiration losses in this area. In this study, the 0.85 in. of water infiltrated the sediments and transported radionuclides through the unsaturated zone. Average meteorologic conditions were assumed to prevail throughout the time period simulated, and no attempt was made to evaluate the effects of extreme storm events. A transit time through the unsaturated zone (~470 ft) was estimated to be approximately 100 yr.

The volume of the shallow perched water zone was estimated by Morris and others (1964) to be equivalent to 3 weeks of discharge to the Warm Waste Pond. The volume of water in the deep perched water zone was estimated to be equivalent to 1.5 to 4 yr of disposal depending on whether an effective porosity of 3.5% (Nace and others, 1956) or a total porosity of 10% was used for the basalt.

The volume of water in the deep perched water zone in April 1988 can be calculated from the configuration of the water table, Figure 17, and an assumption of the porosity. Using a range of porosity for the basalt from 3.5% to 10%, the volume of water in the deep perched water zone in April 1988 was between 178 million and 508 million gal of water. The volume of water disposed of in 1987 was 209 million gal. Storage in the deep perched water zone would therefore be equivalent to between 10 and 29 months of discharge to the surface ponds.

Water Quality

Water in the Snake River Plain Aquifer shows a chemical composition reflecting the source area of the recharge (Robertson and others, 1974). Recharge from the north and northwest is derived from clastic and carbonate sedimentary rocks and is a calcium-bicarbonate type water. Recharge from the east is derived from silicious volcanic rocks and is somewhat higher in sodium, fluoride, and silica. Groundwater at TRA is of the calcium-bicarbonate type (Figure 18), indicative of recharge from the north and northwest. The natural water quality has been altered somewhat by disposal of waste waters from TRA and from the Naval Reactor Facility (NRF) some 4.7 miles northeast of TRA.

Figure 19 shows the distribution of specific conductance in the groundwater in the south-central INEL, near TRA. Specific conductance is a measure of the total dissolved ionized salts in the water. Findings of elevated specific conductance show that areas of the aquifer have been impacted by waste disposal activities. The major constituents in waste water that contribute to the elevated specific conductance are sodium,

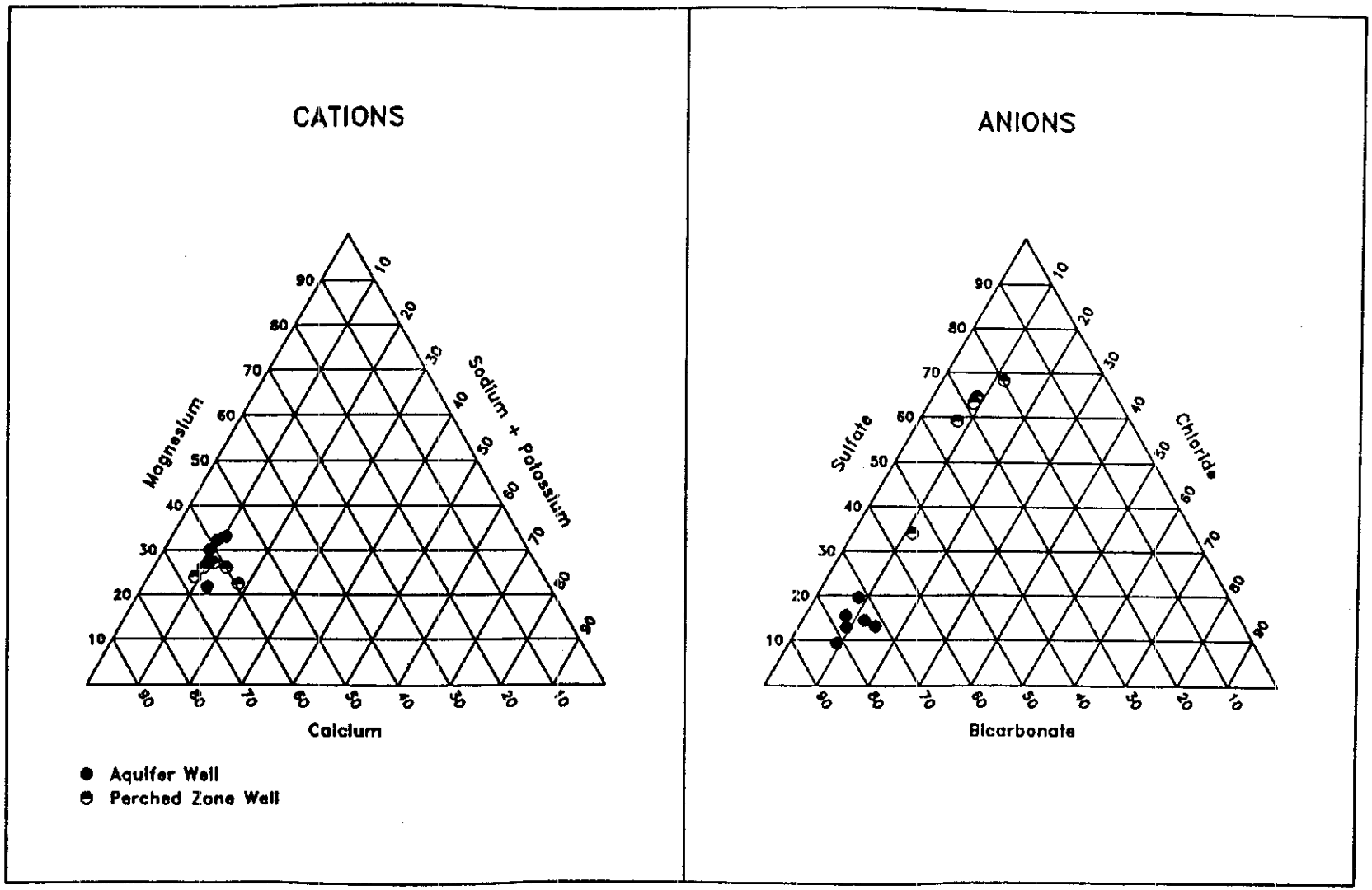


Figure 18. Percent ionic composition of groundwater from the Snake River Plain Aquifer and the deep perched zone at TRA.

chloride, nitrate, and sulfate. These salts primarily come from regeneration of ion exchange columns and water softeners.

Water in the deep perched water zone at TRA is groundwater that has been pumped from the aquifer, used for various purposes, then discharged to ponds on the surface. Based on a comparison of perched water composition to groundwater composition (Figure 18), the most significant component added to perched water is sulfate, which is likely derived from sulfuric acid used to regenerate ion exchange columns. The pH of water in the perched water zone is about 8, so any acid disposed is neutralized.

In spite of the addition of large quantities of sodium hydroxide and sodium chloride to the waste water at TRA, there is no significant change in the relative cation composition of the perched groundwater nor in the chloride content of the water. The maximum increase in the percent of sodium in the perched groundwater is 10%. The buffering of groundwater composition relative to waste stream water composition may reflect a significant reservoir of calcium and magnesium in surficial sediments for ion exchange with sodium and hydrogen ions from the waste water.

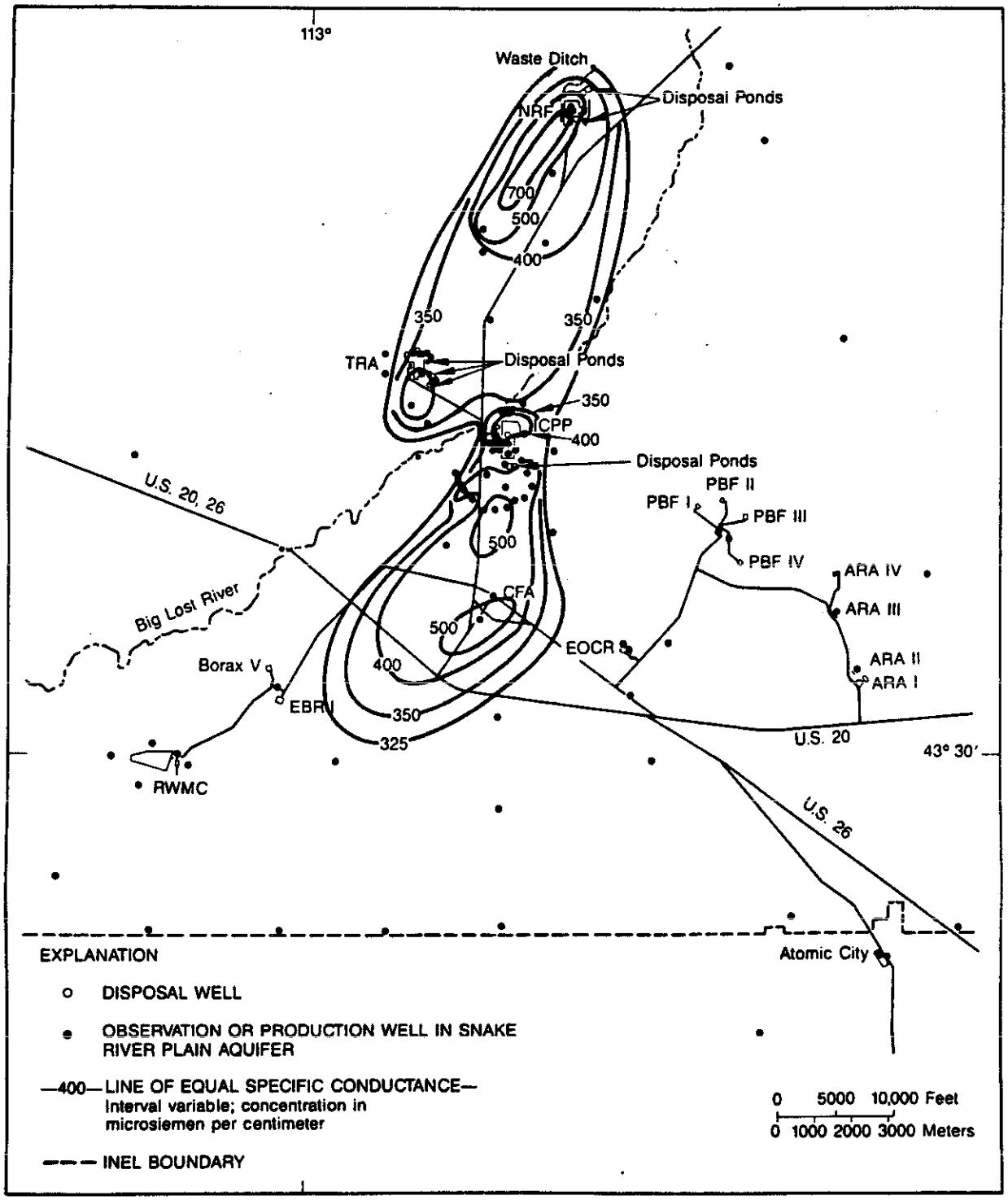


Figure 19. Distribution of specific conductance of groundwater near TRA, October 1985 (Pittman and others, 1988).

Demography and Land Use

Human Receptors

Human Access. The TRA Warm Waste Pond is located on federally owned land that has been withdrawn from public use by DOE. Public access to the INEL is limited to two federal highways and three state highways (Figure 2). Other roads within the INEL boundary are restricted to use by INEL personnel and visitors on official business. All roads within the INEL boundary are patrolled by on-site security personnel. The Arco branch of the Union Pacific Railroad crosses the southwest corner of the INEL. A spur from this line extends north through the Central Facilities Area (CFA) to the Naval Reactors Facility (NRF) with a side spur to the ICPP. DOE has the authority to control traffic on the roads and railroads on the INEL during normal operations and in the event of an emergency.

Residential Population Distribution. No resident populations are located within the INEL site boundary. The nearest permanent residents are in Atomic City (1980 population: 35), located approximately 12 miles from the TRA Warm Waste Pond. Other population centers in the vicinity of the INEL include Idaho Falls (1980 population: 39,739), located 45 miles east of the INEL; Blackfoot (1980 population: 10,065), located 41 miles southeast; and Arco (1980 population: 1241), located 17.5 miles west of the INEL.

The 1980 population within 50 miles of the TRA Warm Waste Pond was 99,571 (see Figure 20 for population distribution). Estimated growth rates since 1980 for the population located within 50 miles vary from -4.8% (for Butte County) to 34.1% (for Blaine County). The estimated population within 50 miles in 1989, based on projections from the Idaho Department of Labor and the U.S. Bureau of Census, is approximately 110,880.

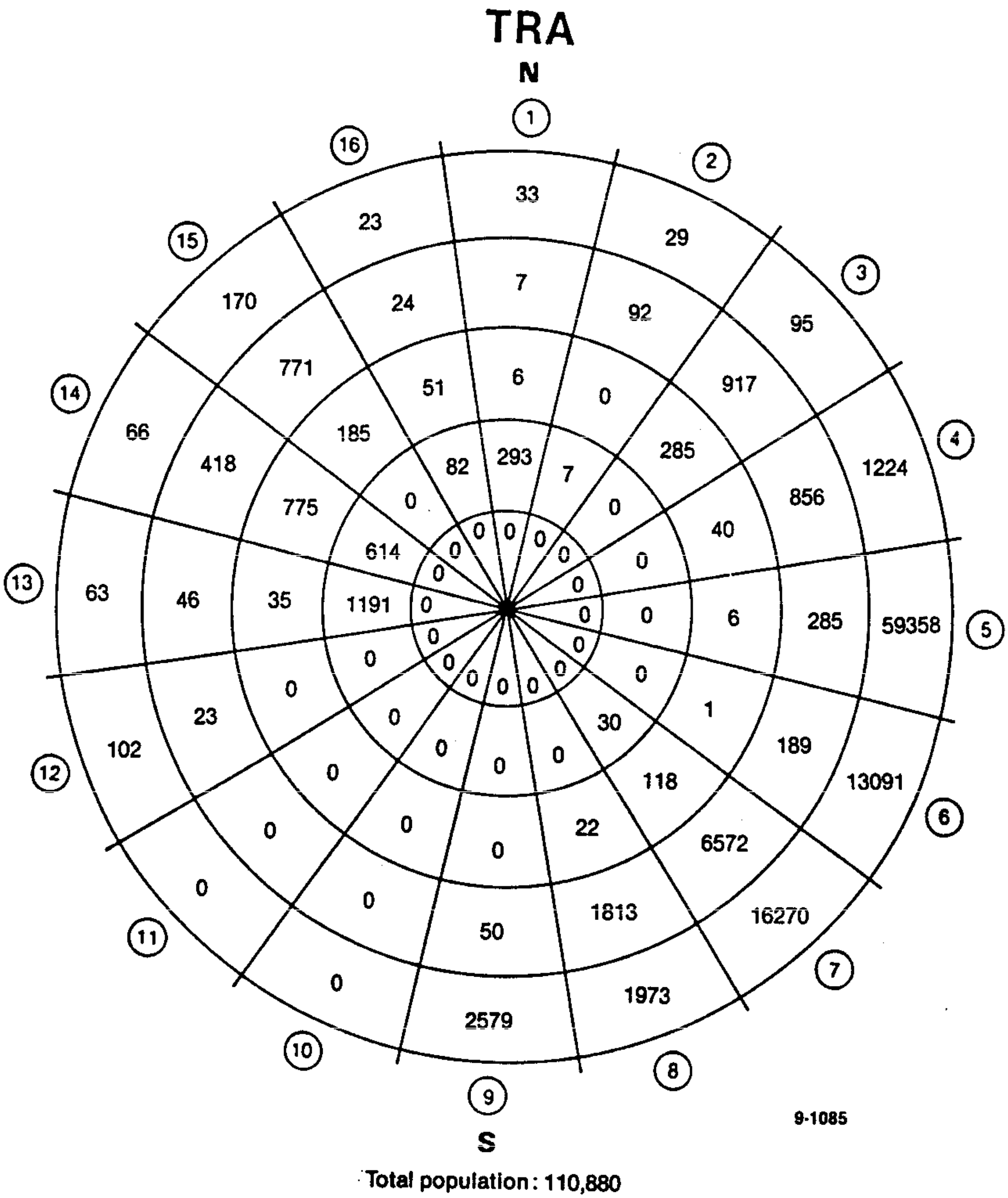


Figure 20. Population distribution centered at TRA in 1989 based on Idaho Department of Labor data.

Non-Residential Population Distribution. Transient populations at the INEL consist of workers at various DOE facilities, stock herdsmen, and hunters. There are approximately 4300 employees working during the day shifts and 950 during the night shifts at the INEL. TRA employs about 500 people and the ICPP, 1.5 miles to the southeast, employs 1500 people, including construction workers. The next nearest facility is CFA, 3.75 miles south, which employs approximately 1100 people, and the Power Burst Facility (PBF), 4.75 miles southeast, which employs approximately 100 people.

Livestock grazing is permitted in areas along the perimeter of the INEL, and herdsmen are likely to be present on the east and south grazing areas during winter and to the west during the warmer months of the year. The nearest possible location for a herdsman would be the grazing boundary 3.5 miles west of the Warm Waste Pond.

The INEL has recently (1989) established an agreement with the Idaho Department of Fish and Game that allows depredation hunts of primarily pronghorn antelope in selected years. The temporary hunting zone extends 0.5 mile inside the INEL boundary along portions of the northeast and west boundary lines. It is difficult to anticipate the number of individuals that will choose to hunt within the temporary zone. A total of 730 tags can be issued for all of Hunting Unit 63, which includes the temporary zone. The 1989 hunt dates for antelope vary for each hunt area within Unit 63, beginning on August 12 and ending November 12. The nearest hunting boundary to the TRA Warm Waste Pond is approximately 7.2 miles, which is the standard INEL boundary.

Land Use

A variety of irrigated and non-irrigated cropland is located within 50 miles of INEL, including forage crops, grain, sugar beets, and potatoes. The nearest cropland is located approximately 11 miles

southeast, near the town of Atomic City, and is irrigated from ground water wells. Site-specific land use information within the 50-mile radius is not available at this time.

Approximately 330,000 acres of the INEL are open to controlled grazing by cattle or sheep (Figure 21). Sheep are grazed on large common sheep allotments (180,419 acres) administered by the Bureau of Land Management along the east and southeast boundaries. Cattle are primarily grazed along the western boundary of the INEL. The nearest grazing boundary is approximately 3.5 miles from the Warm Waste Pond.

Dairy cattle are found within a 50-mile radius of the Warm Waste Pond but primarily at distances greater than 30 miles. The closest dairy production is between 10 to 20 miles away and cannot be more precisely located at this time.

Water Use and Supply

The Snake River Plain Aquifer underlies the Snake River Plain and the INEL. The aquifer is approximately 200 miles long and 30 to 60 miles wide, comprising an area of about 9600 miles^2. The aquifer is heterogeneous, composed of thin basalt flows with interbedded layers of sediment. The distance from the surface to the aquifer is about 450 ft at the TRA and varies from 200 ft in the northeast corner of the INEL to 900 ft in the southwest corner of the INEL.

The aquifer not only provides water for INEL operations, but also supplies agriculture and other industries. The visitor center at the Experimental Breeder Reactor No. I (EBR-I), a national historic landmark 6 miles southwest of the ICPP, and the rest stop on U.S. Highway 20/26 at the Big Lost River crossing, 4 miles west-southwest of the TRA, are also supplied with drinking water from the aquifer. Other withdrawals from the aquifer downgradient of the TRA occur at two wells that serve the Central Facilities Area (CFA) and the well serving the INEL Firing Range. Atomic City, Idaho, 11 miles southeast of the TRA depends on the aquifer for both domestic and irrigation water supplies. Water from springs emerging in the

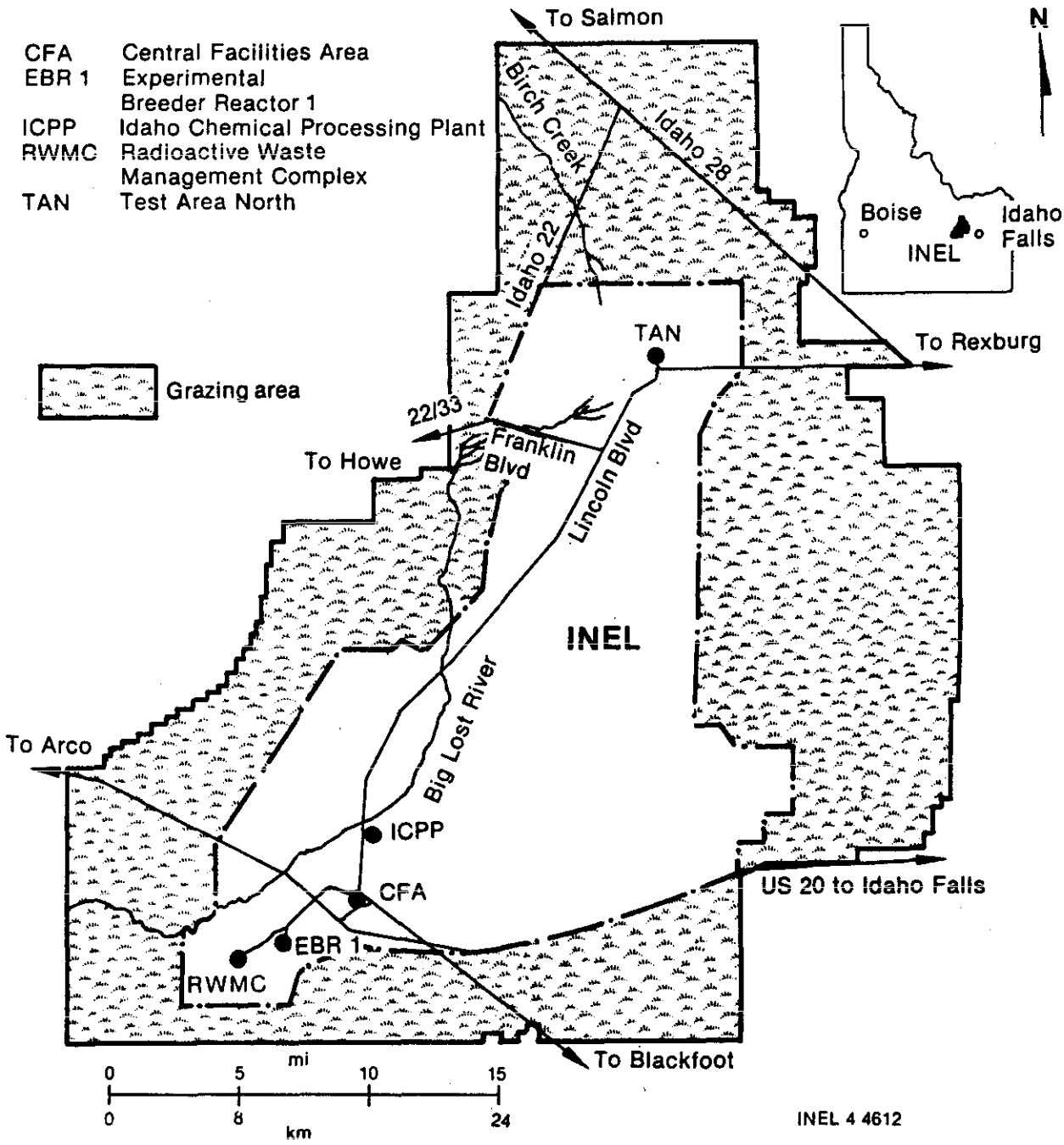


Figure 21. Permit grazing areas at the INEL.

Twin Falls-Hagerman, Idaho, area is used to raise fish commercially. The springs' water flow of 1600 cfs constitutes 76% of the water used for the commercial production of fish in Idaho. The Twin Falls-Hagerman area is some 75 miles down gradient from the INEL. At flow rates of 5 to 11 ft/day, the travel time would be from 100 to 200 yr.

Three production wells at TRA (Wells 1, 3, and 4 in the northeast corner of the facility) supply water for all uses, including drinking water. These wells are completed in the regional aquifer and upgradient from sources of contamination, such as the Disposal Well and the Warm Waste Pond. Calculations were performed by Morris and others (1965) to determine the potential impact of the Disposal Well on these production wells. That study concluded that, in spite of production rates of almost 3,000,000 gpd and injection rates on the order of 1,500,000 gpd, the buildup from the Disposal Well was not expected to intercept the cone of depression around the production wells. Chromium concentrations in the production wells were low at the time injection began. From more recent measurements, it is apparent that chromium did reach the production wells. The most likely source is the Disposal Well since the chromium concentration increased without a similar increase in tritium in the production wells. Chromium from the Warm Waste Pond would likely have reached the wells prior to 1962 and would be associated with tritium disposed into the pond. After chromium use was ended in 1972, there was a decline in chromium concentration in the production wells that lagged several years behind cessation of chromium use. Since 1982, when use of the Disposal Well stopped, chromium no longer appears to migrate to the production wells.

In addition to the production wells at TRA, there are production wells at the Central Facilities Area (CFA). The CFA production wells are downgradient from TRA (Figure 13), but are not in the direct path of flow lines passing through TRA and along, which contaminants from the Disposal Well or Warm Waste Pond would travel. Other production wells that might be downgradient from TRA are the EBR-I well, the firing range well, the rest stop well on Highway 20/26 and the production well at the RWMC.

Ecology

Flora

McBride and others (1978) described 20 distinct vegetative cover types on the INEL. The dominant species (covering approximately 80% of the area) is big sagebrush (Artemisia tridentata). Other shrubs, including green rabbitbrush (Chrysothamnus viscidiflorus), are also common in some areas. Grasses include bluebunch wheatgrass (Agropyron spicatum), thickspike wheatgrass (Agropyron dasystachyum), bottlebrush squirrel tail (Sitanion hystrix), needle-and thread grass (Stipa comata), and Indian ricegrass (Oryzopsis hymenoides) (McBride and others, 1978; Anderson and Holte, 1981).

A plant species inventory containing 399 species representing 56 botanical families and 213 genera has been documented at the INEL (Jeppson and Holte, 1978; Cholewa and Henderson, 1984). The most diversified botanical family represented is the sunflower family. Riparian vegetation occurs along the Big Lost River, Little Lost River, and Birch Creek.

Fauna

The variety of habitats on the INEL supports numerous species of reptiles, birds, and mammals. Common herbivorous mammals are the white-footed deer mouse (Peromyscus maniculatus), Ord's kangaroo rat (Dipodomys ordii), montane vole (Microtus montanus), Townsend's ground squirrel (Spermophilus townsendii), least chipmunk (Eutamias minimus), cottontail rabbit (Sylvilagus nuttallii), and blacktailed jackrabbit (Lepus californicus). The pronghorn (Antilocapra americana) and mule deer (Odocoileus hemionus) also are found in the area. The pronghorn is migratory (Hoskinson and Tester, 1980). During some years, up to 30% of Idaho's pronghorn herd winters on the INEL (Reynolds and Rose, 1978).

Predatory mammals in the area include the coyote (Canis latrans), long-tailed weasel (Mustela frenata), badger (Taxidea taxus), and bobcat (Lynx rufus).

Although hunting is not permitted on the site (except for planned depredation hunts for pronghorn antelope), common game birds are the sage grouse (Centrocercus urosphasianus) and mourning dove (Zenaida macroura). Passerine birds, such as the horned lark (Eremophila alpestris), western meadowlark (Sturnella neglecta), sage thrasher (Oreoscoptes montanus), and loggerhead shrike (Lanius ludovicianus), also frequent the INEL. Several species of owls, hawks, falcons, and eagles occur on the INEL.

The most common reptilian inhabitants on the site include the sagebrush lizard (Sceloporus graciosus), short-horned lizard (Phrynosoma douglassi), Great Basin rattlesnake (Crotalus viridis), and Great Basin gopher snake (Pituophis melanoleucus) (Sehman and Linder, 1978). The only amphibian observed on the INEL is the Great Basin spadefoot toad (Spea intermontana) (EG&G, 1984).

A diverse insect population is associated with sagebrush communities and is an integral part of the rangeland ecosystem. Insects play an important role in food chains of the INEL ecosystem (Halford, 1981).

Aquatic life at the INEL site is affected by the flow of the Big Lost River. During several months of the year, and even during some entire years, the river is dry on the INEL. However, during spring runoff and periods of heavy rainfall, water can accumulate in the diversion system located approximately 10 miles southwest of the TRA and in the Big Lost River sinks located approximately 16 miles north of the TRA. The accumulated water provides temporary habitat for some wildlife species. Common fish species in the Big Lost River are rainbow trout (Salmo gairdneri), mountain whitefish (Prosopium williamsoni), and shorthead sculpin (Cottus confusus).

Endangered Species

No plants on the Federal list of endangered or threatened species have been observed on the site. However, a 1981 survey of the INEL by Cholewa and Henderson (1984) discovered two species of milk vetch currently under federal review for endangered or threatened status. These are Astragalus

ceramics var. apus and A. pushii var. ophigenes. Seven other species identified are on the State of Idaho watch list. These species are A. gilviflorus, A. kentrophyta var. jessiae, Coryphantha missouriensis, Gilia polycladon, Gymnosteris nudicaulis, Lesquerella kingsii var. cobrensis, and Oxytheca dendroidea.

Endangered species occasionally observed at the INEL site are the bald eagle (Haliaeetus leucocephalus) and the peregrine falcon (Falco peregrinus). Several species are listed as species of special concern by the State of Idaho occur on the INEL: bobcat, ferruginous hawk (Buteo regalis), long-billed curlew (Numenius americanus), and the merlin (Falco columbarius) (Gleisner, 1983). None of these endangered species is known to reside at the TRA.

INITIAL EVALUATION

This section presents data on the distribution of radionuclides and toxic metals in sediment and groundwater at TRA. Data are compiled from analysis of the pond sediments sampled in the summers of 1987 and 1988 and from USGS monitoring activities. The data are compiled into a site conceptual model which can be used to evaluate potential health and environmental impacts posed by the site.

Types and Volumes of Wastes

Waste Inventory

The Warm Waste Pond has received both industrial and radioactive waste streams since its construction in 1952. In recent years, detailed records have been kept of the quantities of wastes disposed in the ponds. These records are maintained in two databases, the Radioactive Waste Management Information System (RWMIS) and the Industrial Waste Management Information System (IWMIS). Few records exist of early disposal practices. The major waste of concern is chromium, which was used as a corrosion inhibitor in cooling waters prior to 1972. Radionuclides were also disposed to the pond. By compiling existing data and estimating previous disposal practices, an inventory of wastes can be derived.

Waste water containing chromium was discharged to the Warm Waste Ponds between 1952 and 1964. From November 1964 to September 1972, the chromium-containing waste streams were introduced directly into the aquifer through the TRA Disposal Well. A major source of nonradioactive waste water was reactor secondary cooling systems. Prior to 1972, chromates were added to those secondary cooling systems as a means of corrosion control, with resultant hexavalent chromium [Cr(VI)] concentrations in the 11 to 14 mg/L range. The secondary system waste stream was combined with cooling tower blowdown streams containing between 4 and 5 mg/L chromate. Further dilution from other waste streams occurred before discharge into the well,

where waste water with an average Cr(VI) concentration between 0.7 and 2 mg/L was injected. Seventy-five samples of water discharged to the well in 1970 and 1971 averaged 1.4 mg/L total chromium concentration. In September 1972, chromium use was stopped in favor of a phosphate-based water treatment process. Cooling water containing the phosphate corrosion inhibitor was discharged into the Disposal Well until 1982. Table 6 shows the estimated amounts of Cr(VI) disposed from TRA facilities. About 40% of the Cr(VI) waste from TRA during the 20 yr of chromate usage was discharged to the Warm Waste Pond.

TABLE 6. ESTIMATED AMOUNT OF Cr(VI) IN kg DISCHARGED AT TRA

Year	System	MTR	ETR	ATR	Total		
1952	Warm Waste Pond	168	--	--	168		
1953		221	--	--	221		
1954		221	--	--	221		
1955		247	--	--	247		
1956		298	--	--	298		
1957		298	--	--	298		
1958		298	1064	--	1362		
1959		298	1064	--	1362		
1960		298	1064	--	1362		
1961		298	1064	--	1362		
1962		298	1064	--	1362		
1963		298	1064	--	1362		
1964		298	1064	--	1362	10,987	Total
1965	Disposal Well	298	1064	--	1362		
1966		298	1064	--	1362		
1967		298	1064	--	1362		
1968		298	1064	--	1362		
1969		298	1064	752	2114		
1970		273	1064	1290	2627		
1971		--	1064	1290	2354		
1972		--	718	860	1578	14,121	Total
				TOTAL	25,108		

Measurements of radionuclides disposed in the pond indicate that some 33,000 Ci were discharged to the pond between 1961 and 1985. While a broad range of radionuclides have been discharged into the pond, this analysis will concentrate on those disposed in the greatest quantities or that have the longer half-lives. Radionuclides with a half-life of a few months or less generally decay before they can migrate a significant distance. Records of radioactive wastes disposed to the Warm Waste Pond have been kept since 1961. These data are maintained in the RWMIS at the INEL and are published in annual reports. Table 7 shows the quantities of selected radionuclides disposed in the Warm Waste Pond. The radionuclides listed are those with relatively long half-lives (generally several years to 30 years) and that have been disposed in significant quantities. Missing data prior to 1961 were estimated by assuming that the average discharge for the period 1961 to 1970 was representative of the period prior to 1961. The left side of Table 7 shows the curies of each radionuclide disposed to the pond in each year; the right side shows the potential inventory of radionuclides, corrected for radioactive decay, that would remain in the pond sediments in 1988. For example, approximately half the Sr-90 (half-life of 29 yr) disposed in 1960 would have decayed by 1989.

The accuracy of some of the data in Table 7 may be questionable. In 1970, Schmalz (1972) sampled the bottom of the Warm Waste Pond and estimated that the pond contained some 700 Ci of Co-60. Based on the data in Table 7, only about 160 Ci would have been present in the bottom of the pond after correcting for radioactive decay. Therefore, the inventory of disposed radionuclides should be considered an approximation.

The effect of half-life on the inventory in the pond sediments is exemplified well by Cr-51, which has a half live of 27.7 days. Note that despite the disposal of many curies of Cr-51, the total concentration is zero. With such a short half-life, there is no carryover of Cr-51 from year to year. Radionuclides with half-lives of one month to several months will not significantly contribute to the radionuclide inventory in the pond sediments, once disposal has ceased.

TABLE 7. YEARLY DISCHARGE OF SELECTED RADIONUCLIDES TO THE WARM WASTE POND[a]

	Total Disposed						1988 Decayed Value					
	CO-60	CR-51	CS-134	CS-137	H-3	SR-90	CO-60	CR-51	CS-134	CS-137	H-3	SR-90
YEAR	Curies						Curies					
1952	22.60	101.50	1.06	0.0	5.8	0.1	0.20	0.00	0.00	0.0	0.8	0.0
1953	22.60	101.50	1.06	1.0	19.9	0.1	0.23	0.00	0.00	0.4	2.8	0.0
1954	22.60	101.50	1.06	3.0	105.0	0.8	0.26	0.00	0.00	1.4	15.4	0.4
1955	22.60	101.50	1.06	3.0	114.3	0.9	0.29	0.00	0.00	1.4	17.7	0.4
1956	22.60	101.50	1.06	2.0	77.2	0.6	0.34	0.00	0.00	1.0	12.7	0.3
1957	22.60	101.50	1.06	2.0	88.5	0.7	0.38	0.00	0.00	1.0	15.4	0.3
1958	22.60	101.50	1.06	7.0	282.7	2.1	0.44	0.00	0.00	3.5	51.9	1.0
1959	22.60	101.50	1.06	11.00	425.8	3.3	0.50	0.00	0.00	5.65	82.7	1.6
1960	22.60	101.50	1.06	13.00	316.4	0.7	0.57	0.00	0.00	6.83	65.0	0.4
1961	22.60	115.60	0.88	11.00	303.00	1.30	0.65	0.00	0.00	5.91	65.91	0.68
1962	36.21	204.25	0.32	8.25	279.02	0.86	1.19	0.00	0.00	4.54	64.22	0.46
1963	13.77	127.08	0.27	6.31	352.99	1.07	0.51	0.00	0.00	3.55	85.96	0.59
1964	39.52	56.58	1.01	5.10	421.29	0.81	1.68	0.00	0.00	2.94	108.56	0.46
1965	14.22	32.73	1.71	5.95	328.47	1.52	0.69	0.00	0.00	3.51	89.56	0.87
1966	7.65	121.61	3.35	3.99	397.89	1.70	0.42	0.00	0.00	2.40	114.80	1.00
1967	33.54	57.79	0.15	4.97	424.36	26.90	2.12	0.00	0.00	3.06	129.55	16.22
1968	22.23	35.52	0.44	4.27	521.70	2.92	1.60	0.00	0.00	2.70	168.53	1.80
1969	20.95	66.98	0.74	11.42	749.17	8.11	1.72	0.00	0.00	7.38	256.07	5.13
1970	16.37	196.87	1.75	5.47	653.27	7.17	1.54	0.00	0.00	3.61	236.27	4.65
1971	4.34	234.75	1.47	10.10	342.20	14.55	0.46	0.00	0.00	6.83	130.96	9.66
1972	1.86	249.68	2.11	6.57	176.30	9.36	0.23	0.00	0.01	4.54	71.39	6.37
1973	3.97	322.44	2.35	3.93	184.43	4.23	0.55	0.00	0.02	2.78	79.03	2.95
1974	2.94	1343.61	1.03	3.44	239.87	0.30	0.47	0.00	0.01	2.50	108.75	0.21
1975	4.30	1693.95	0.59	2.93	260.24	---[b]	0.78	0.00	0.01	2.17	124.85	0.00

TABLE 7. (continued)

YEAR	Total Disposed CO-60 (Curies)	CR-51 (Curies)	CS-134 (Curies)	CS-137 (Curies)	H-3 (Curies)	SR-90 (Curies)	1988 Decayed Value CO-60 (Curies)	CR-51 (Curies)	CS-134 (Curies)	CS-137 (Curies)	H-3 (Curies)	SR-90 (Curies)
1976	3.51	2,566.69	0.39	1.97	292.95	0.21	0.72	0.00	0.01	1.50	148.71	0.16
1977	4.75	1,074.21	0.41	2.73	139.62	---[b]	1.12	0.00	0.01	2.12	74.99	0.00
1978	1.31	1,052.20	2.90	6.93	125.55	3.38	0.35	0.00	0.10	5.51	71.36	2.65
1979	3.50	1,343.31	0.52	1.71	105.36	1.67	1.07	0.00	0.03	1.39	63.36	1.34
1980	3.15	94.23	0.37	2.80	135.03	1.57	1.10	0.00	0.02	2.33	85.93	1.30
1981	0.68	13.10	0.22	1.48	190.81	0.52	0.27	0.00	0.02	1.26	128.48	0.44
1982	1.40	45.99	0.05	1.26	514.83	0.79	0.63	0.00	0.01	1.09	366.81	0.69
1983	1.17	22.84	0.04	0.58	202.84	0.56	0.61	0.00	0.01	0.52	152.92	0.49
1984	0.67	7.80	0.11	0.59	161.22	0.34	0.40	0.00	0.03	0.53	128.61	0.31
1985	0.72	6.67	0.03	0.19	260.60	0.03	0.49	0.00	0.01	0.18	219.97	0.03
1986	1.26	12.49	0.00	0.06	76.71	0.04	0.97	0.00	0.00	0.06	68.51	0.04
1987	0.13	8.02	0.04	0.65	127.83	0.08	0.11	0.00	0.03	0.63	120.81	0.08
Totals	471	12,020	33	157	9,403	99	26.	0	0	97	3,729	63

a. Data from 1961 through 1987 are taken from Osloond (1970) and from the RWMIS database maintained at the INEL for radioactive waste. Data for Sr-90 and Cs-137 from 1952 to 1960 are from Schmalz (1972). Data for H-3 from 1952 to 1960 are estimated using 9.2% of gross beta-gamma radiation (Barraclough and others, 1967). Data for Co-60, Cr-51, and Cs-134 from 1952 to 1960 are estimated using the mean of the 1960 to 1970 data.

b. Missing data.

Geochemistry of Chromium. Chromium has several possible oxidation states. The hexavalent and trivalent oxidation states are the most likely to occur in groundwater (Hem, 1970). Thermodynamic data indicate that the hexavalent state is stable in groundwater that is in equilibrium with air (Figure 22). The hexavalent form of chromium is very mobile in water because it is present as an anion at neutral pH; once reduced to the trivalent state, however, it is much less mobile. Trivalent chromium is a cation in groundwater and can be retarded by either ion exchange on sediments or precipitation as a solid phase, $Cr(OH)_3$. The solubility of $Cr(OH)_3$ theoretically limits the concentration of chromium to very low values. Figure 23 shows the concentration of trivalent chromium in water in equilibrium with $Cr(OH)_3$ as a function of pH. At pH values representative of INEL groundwater (pH 7.5 - 8.0), the low solubility of chromium results in precipitation and, therefore, low levels of chromium in solution. The net result is chromium concentrations in the water seven orders of magnitude below regulatory limits.

Hexavalent chromium can be reduced to the trivalent state in the presence of reduced iron and sulfur species (Eary and Rai, 1988; Schroeder and Lee, 1975) or by readily oxidizable organic matter (Zachara and others, 1989). Thus, hexavalent chromium discharged to the Warm Waste Pond could have been reduced, particularly by organic matter in the pond sediments, removed from the infiltrating water, and deposited on sediment surfaces by ion exchange or precipitation. Trivalent chromium will oxidize slowly in the presence of oxygen or MnO_2 (Schroeder and Lee, 1975). Manganese dioxide is a common constituent of INEL soils.

Half-lives and Relative Mobility of Radionuclides. Table 8 gives the half-lives of the radionuclides discussed in this report. Also shown in that table are the sorption coefficients and retardation factors that

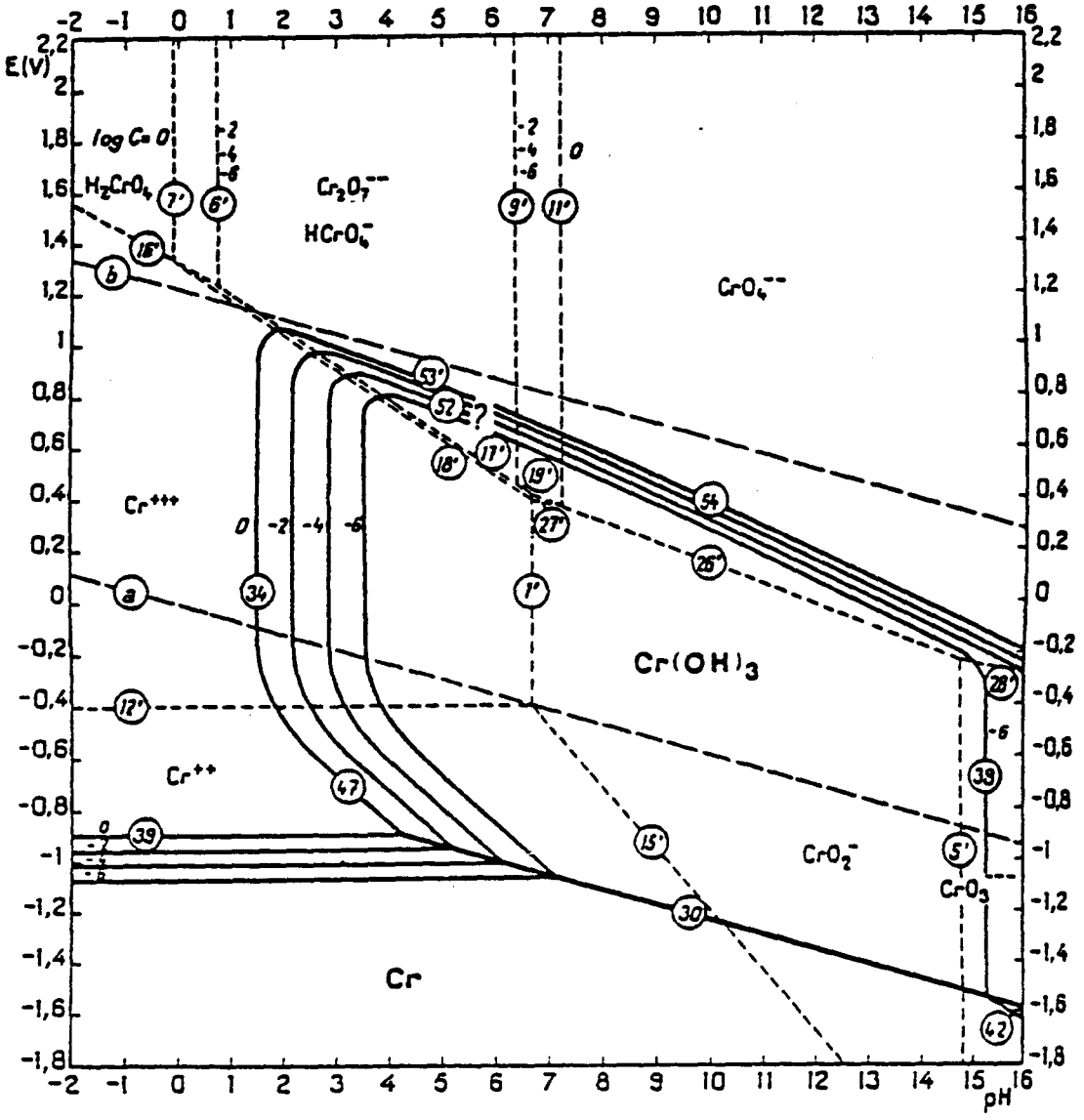


Figure 22. Redox potential and pH conditions under which various forms of chromium are stable (Pourbaix, 1974). The line labeled "b" represents water in equilibrium with air, and most closely represents groundwater and vadose zone conditions at the INEL.

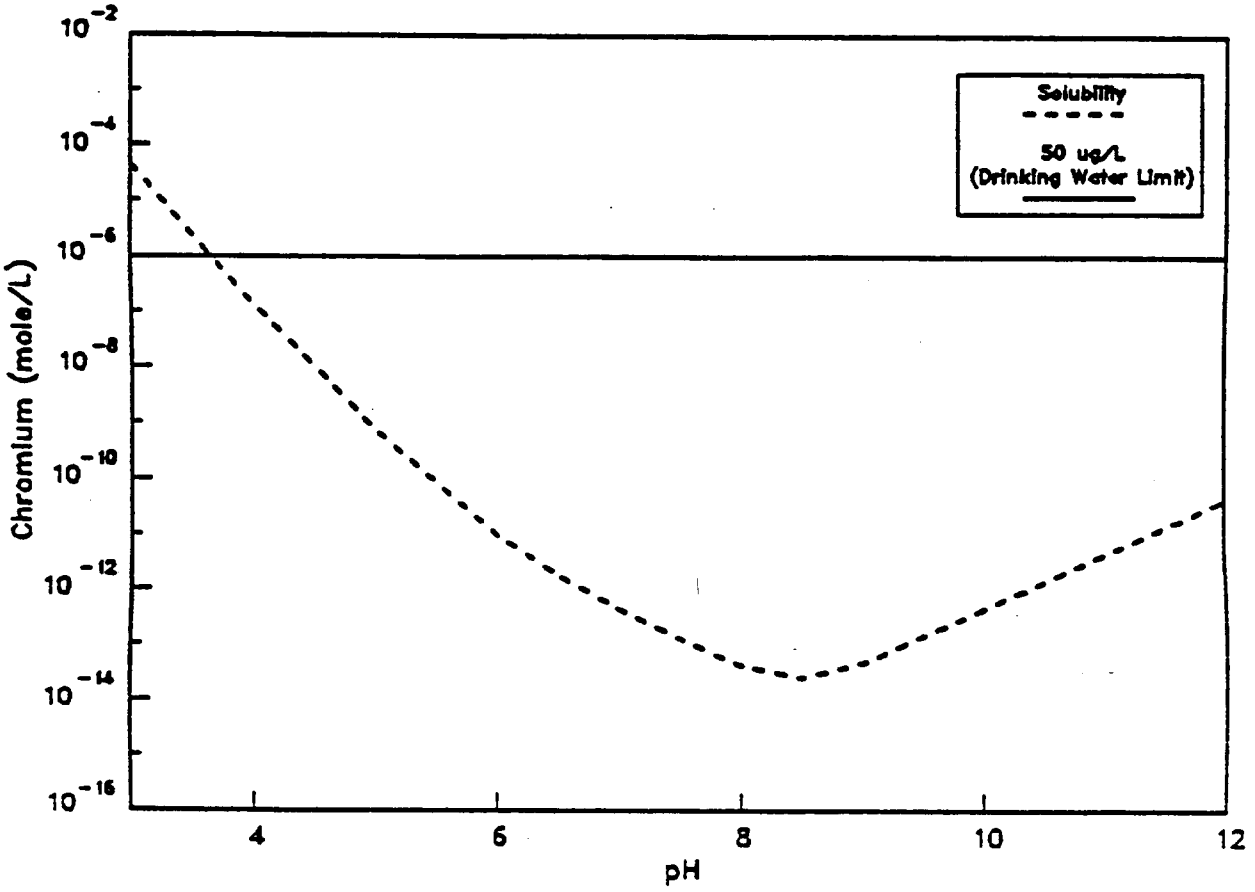


Figure 23. Solubility of trivalent chromium in water in equilibrium with $Cr(OH)_3$ at 25°C. At pH values near 8.0, the solubility of chromium in water is about seven orders of magnitude below the drinking water standard.

TABLE 8. HALF-LIVES, SORPTION COEFFICIENTS, AND RETARDATION FACTORS FOR RADIONUCLIDES OF CONCERN AT THE TRA WARM WASTE POND (Staley and others,1979; Isherwood, 1981)

Nuclide	Half Life (yr)	K_d (mL/gm)	Retardation Factor[a]
Cr-51	0.075	10	56
Co-60	5.3	100	550
Cs-134	2.06	20	110
Cs-137	30.1	20	110
H-3	12.26	0	1
Sr-90	29	2	12
Am-241	433	70	380
Cm-244	17.9	70	380
U-232	72	150	820
U-234	2.44E+05	150	820
U-238	4.47E+09	150	820
Pu-238	87.8	200	1100
Pu-239	24,400	200	1100

a. Retardation factors calculated using ρ = 1.80 gm/cm^3, θ = 0.33, average values from Table 4.

characterize the relative mobility of the radionuclides. The sorption coefficient describes the distribution of a radionuclide between water and soil materials:

$$K_d = \frac{C_s}{C_l} \qquad (3)$$

where

K_d = sorption coefficient (mL/gm)
C_s = concentration on solid phase (Ci/gm)
C_l = concentration in solution (Ci/mL).

A radionuclide will travel at a rate that is less than the rate of water movement due to sorption. This relative rate of travel can be described by the retardation factor:

$$R = 1 + \frac{\rho}{\theta} K_d \qquad (4)$$

where

R = retardation factor (unitless)

ρ = bulk density (gm/cm^3)

θ = porosity (unitless).

Sorption of radionuclides is a surface phenomenon, and K_ds and Rs given in Table 6 are for sorption on porous materials. In fractured media, the surface area in contact with water is much less, easily by a factor of 30. Therefore retardation in fractured media, such as the fractured basalts, could be much less than suggested by the retardation data in Table 8.

Data in Table 8 show that most of the radionuclides will exhibit significant retardation relative to the movement of water. The assumptions involved in sorption coefficients and retardation factors are such that these numbers should only be used to evaluate the relative mobility of the radionuclides, and do not necessarily represent the actual behavior of the radionuclides.

Previous Sampling Activities

Two sampling activities have been conducted at the TRA Warm Waste Pond to characterize the types, concentrations, and distribution of contaminants. The first sampling activity was part of the Preliminary Investigation and was designed to determine maximum contaminant concentrations and to develop a list of indicator contaminants representative of sediments in the TRA Warm Waste Pond. The second investigation was part of the Remedial Response Investigation and was

designed to determine the spatial variation in indicator contaminants in each of the three ponds, and to determine the attenuation of the contaminants with depth. These two investigations are briefly described in this section.

Preliminary Investigation. The objective of the Preliminary Investigation Sediment Sampling was to obtain an estimate of the maximum concentrations of hazardous and radioactive substances in sediment from the TRA Warm Waste Pond. The data were used to identify or confirm hazardous substance content in the sediment of the pond and to narrow the range and cost of feasible remedial investigation sampling analyses that may be appropriate to the release. Prior to sampling, a Health and Safety Plan and a Sampling and Analysis Plan was prepared.

Sampling. The bed of the TRA Warm Waste Pond (Cells 1952-57) is composed of approximately 6 to 15 cm (3 to 6 in.) of sediment on top of coarse alluvial gravel. Six sediment/sludge samples were collected from the bottom of the 1952 and 1957 cells during the preliminary investigation sampling. Samples were not taken from the 1964 cell because it has not been in operation during much of the historical disposal period. Sample sites in the 1952 and 1957 cells were located in probable areas of maximum contaminant concentrations. Details of background soil sampling and analysis have been submitted to the Environmental Protection Agency (EPA) "Background Soil Sampling and Analysis Plan for EG&G Activities" April 24, 1987.

For purposes of this plan it was assumed that contaminants achieve maximum concentrations in the sediment under one of two circumstances. First, where the disposed waste is denser than the pond water (as in the case of dense immiscible organic constituents or concentrated brine), the contaminant may sink to the bottom of the pond very rapidly and enter the sediments. Second, as many contaminants will preferentially be associated with fine-grained materials scavenged by the water from windblown dust deposits or algae, contamination may be concentrated where fine-grained sediments accumulate.

To collect samples representative of the first accumulation mechanism, samples were collected near the pond inflow pipe, just outside any evidence of turbulence in the pond water. Samples representative of the second accumulation mechanism were collected from the bottom of the pond near the transition to the side of the pond. Locations in corners away from inflow and outflow points were given preference. Figure 24 shows the approximate locations that the samples were collected. Six samples were used to identify levels of contaminants in pond sediments.

Sample containers for each sediment sample consisted of four 8-oz wide-mouth amber glass jars with teflon lined lids. The containers were pre-cleaned in the laboratory prior to shipment to the site, according to procedures as specified in the Quality Assurance (QA) Plan for the TRA Warm Waste Pond, Section 4, published in the TRA Warm Waste Pond Corrective Action Workplan (VanDeusen, 1988).

Grab samples of pond sediments were obtained with a stainless steel bucket attached to a pole. Samples were collected by a person standing on the edge of the pond, lowering the bucket into the water, and dragging the bucket slowly along the bottom of the pond. The bucket was retrieved slowly to minimize the amount of fine-grained sediment that washed out of the sampling bucket. A fraction of the sample for volatile analysis was spooned out of the sediment in the sample bucket, placed in the sample container, and the filled sample container was sealed. The volatile sample was taken before decanting or mixing of the sediment in the bucket.

The sampling bucket was used as the mixing container. The sediment was gently mixed with a stainless steel spoon until it was visibly homogeneous. The sediment was spooned into a labeled container. Containers were filled by spooning the sediment, one spoonful at a time, to each of the containers in turn. This procedure provided more homogeneous samples for analysis. The samples were analyzed for all compounds of the 40 CFR 261, Appendix VIII list using EPA approved analytical methodologies and EPA SW-846 procedures. Analysis of a portion of each sample for hexavalent chromium was conducted in a TRA laboratory to adhere to the short 48-hr extraction time required.

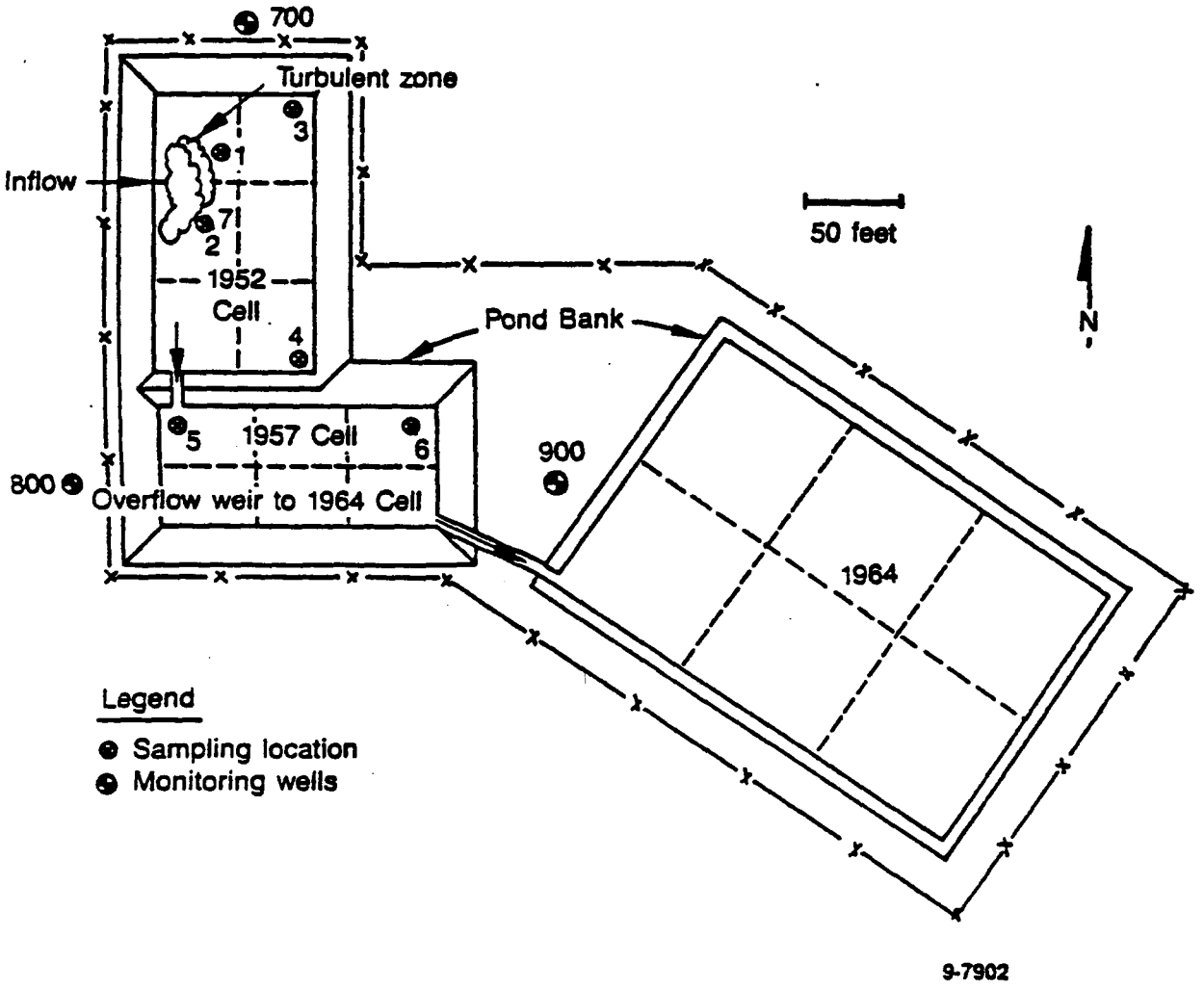


Figure 24. Sediment sampling locations for the Preliminary Investigation at the TRA Warm Waste Pond.

A portion of each sample was transferred to the EG&G Radiation Measurements Laboratory at TRA for gamma-ray spectral analysis. A small quantity of the sludge sample was taken immediately after vigorous stirring. The samples were dried, weighed, and fused with potassium, fluoride, and pyrosulfate. The fused material was dissolved in a 2 M HCl solution. The solution was placed in 540 ml plastic bottles and diluted with water to the neck of the bottle. These samples were counted on Germanium spectrometers at a 5 cm source/detector distance for 1200 to 3600 s. The radionuclide activities were reported in micro-Curies per gram of dried sediment.

Results. Data from the Preliminary Investigation sampling was statistically compared to background using the procedure described by Rehak (1989). Based on the comparison, a number of constituents (Table 9) were identified as being present at concentration levels significantly above background. Since contamination above background was detected in the pond, the Remedial Response Investigation was initiated to better define the nature and extent of contamination at the pond. The Preliminary Response Investigation was directed at those constituents listed in Table 9, rather than the entire suite of Appendix VIII Constituents.

Remedial Response Investigation The Remedial Response Investigation sampling was performed to obtain an estimate of the distribution of hazardous and radioactive constituents in the pond sediment to a depth of 10 ft below the bottom of the pond. Details of the Remedial Response Investigation Plan are included in the TRA Warm Waste Pond Corrective Action Workplan (VanDeusen, 1988)

The remedial investigation was originally proposed to be conducted in three phases with each phase designed to examine strata progressively to greater depths as necessary to identify spatial distribution in surficial sediment and determine contaminant penetration depth. This approach was reasonable, since metallic contaminants are of major concern at the Warm Waste Pond. Metals (e.g., Cr, Pb, Hg) will interact extensively with sediment, with a large percent of the total amount of metal being in the

TABLE 9. CONSTITUENTS IDENTIFIED IN WARM WASTE POND SEDIMENTS TO BE SIGNIFICANTLY ABOVE BACKGROUND LEVELS (Rehak, 1989).

Identified in Preliminary Investigation	Results of Remedial Response Investigation[a]
Acetone	none above background
Acrylonitrile	none above background
Bis(2-ethylhexyl)phthalate	samples above background
Di-n-butylphthalate	none above background
Di-n-octylphthalate	none above background
Pentachlorophenol	none above background
Arsenic	27 samples above background
Beryllium	2 samples above background
Cadmium	10 samples above background
Chromium (total)	47 samples above background
Chromium (hexavalent)	none above detection limit
Cyanide	8 samples above background
Lead	18 samples above background
Mercury	34 samples above background
Silver	21 samples above background
Sulfide	33 samples above background
TOC	12 samples above background
Zinc	7 samples above background

a. The results are based on approximately 88 samples. Actual sample numbers vary for each analyte.

solid phases. It is unlikely that the metals would have travelled any distance without leaving a distinct trail of elevated metal concentrations in sediments. The phased approach is being utilized to minimize costs, since sampling is not conducted at greater depths unless, as a result of analysis of data, additional sampling data is deemed to be necessary.

Spatial variables (such as chromium concentration in the Warm Waste Pond) generally show correlation over a finite distance. When spatial dependence occurs, precision attained by random sampling can usually be improved by systematic sampling (McBratney and Webster, 1983). Samples collected close together tend to be more similar than samples collected far apart. An observation therefore carries with it some information about its neighborhood. When a region is sampled at random, some observations are inevitably very close, duplicating information. A fixed grid with regular spacing provides the maximum amount of information. If the distribution of the contaminant is random, the regular grid is equivalent to the random sample. The general sampling strategy of the remedial investigations will be to use a grid pattern(s) and modified random sampling techniques.

Remedial Investigation, Phase I. Phase I of the remedial investigation involved (a) sampling the sludge and sediment beneath the pond and (b) drilling three auger holes through the layer of surficial sediment adjacent to the Warm Waste Pond (Figure 25). Data on hazardous and radioactive contaminant concentrations underlying and adjacent to the pond were collected.

The sampling strategy used at the Warm Waste Pond in the Remedial Investigation, Phase I, is as follows. Each pond cell was divided into six equal sections in an unaligned grid. Random sampling techniques were used to determine the sampling location in each of the six sections of the grid in each cell of the pond for a total of 18 sampling locations.

At these locations in the cell (intervals on each sample were recorded), samples were collected, representing various layers encountered (including loose upper sediments, gravel/cobble, and underlying natural

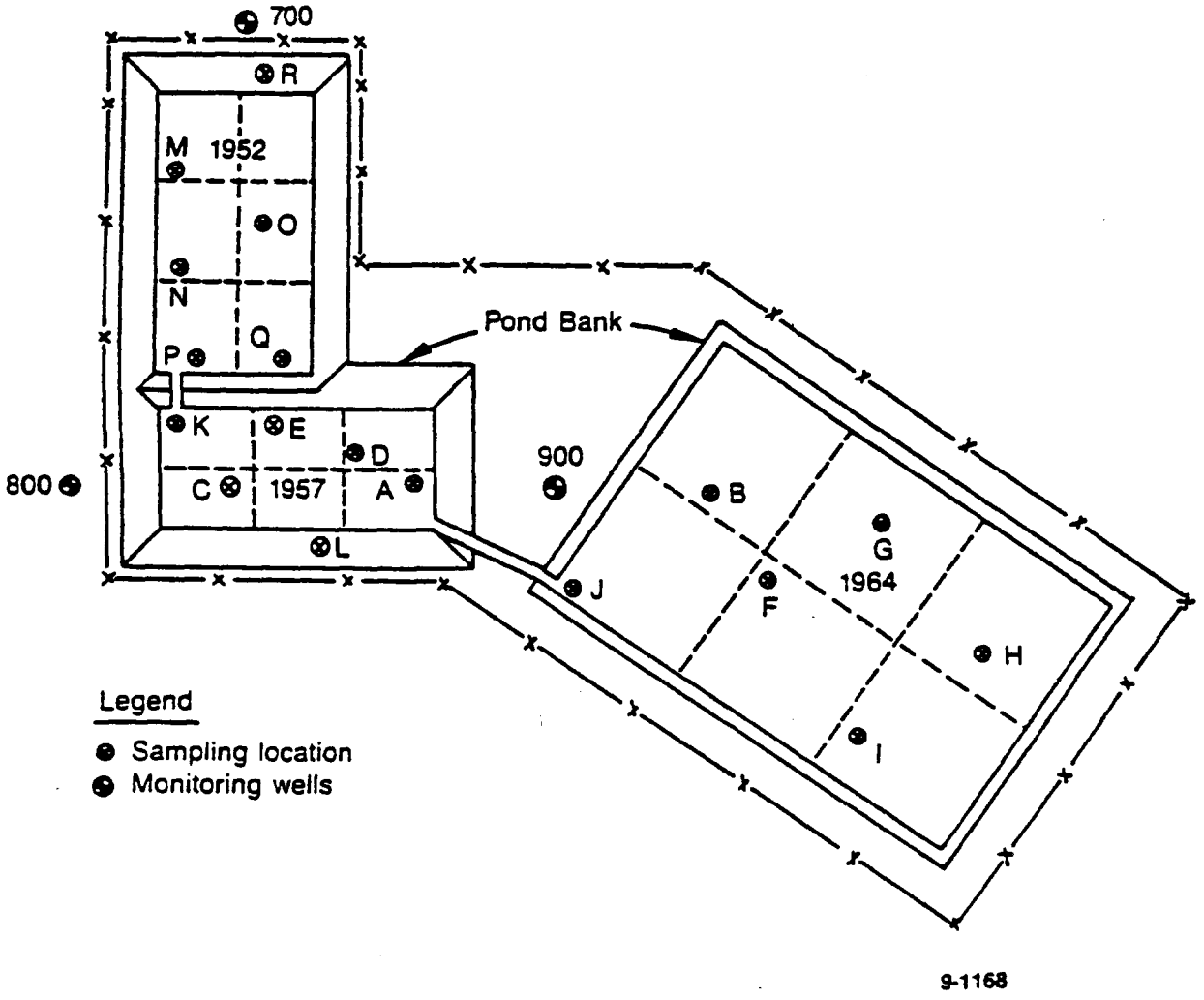


Figure 25. Sediment sampling locations and monitoring well locations for the Remedial Response Investigation, Phase I, at the TRA Warm Waste Pond.

gravel/sand/alluvium) to determine changes in contaminant concentration with depth. Five samples were obtained to approximately 10 ft at the following depths: 0 to 2 ft, 2 to 4 ft, 4 to 6 ft, 6 to 8 ft, and 8 to 10 ft. Since a limited number of samples were available from a split spoon, especially in the gravel beneath the pond cell, two or more cores were sometimes required near a single location to obtain a large enough sample for analysis. Data from preliminary investigation sampling used to determine constituents for analysis dictated the sample size needed.

Sampling of the 1952 and 1957 cells was performed using an 18-ft johnboat. A rectangle "hole" was fabricated in the johnboat to allow sampling through the bottom.

A forklift was used to place the johnboat on the edge of the 1957 cell of the pond. The boat was launched by sliding it down the side of the pond using ropes to control the slide. After the 1957 cell was sampled, a rope attached to a truck outside of the fence was used to pull the boat over the low berm between cells 1952 and 1957.

During sampling of these cells, nylon rope was stretched across the lagoon in two directions and tied to metal fence posts on the shore, to anchor the johnboat over sampling locations. A second boat was used to transport workers and equipment to and from shore. When the boat was anchored over the sampling point, a 3-in. casing was lowered through the fabricated sampling hole in the bottom of the boat. The casing was lowered with a winch and cable system attached to a quadrapod mounted in the johnboat.

A stainless steel bailer was used to remove the water from inside the casing. A 2.5 x 24 in. stainless steel split spoon was inserted inside the casing and driven 2 ft to collect a sample. The split spoon was driven using a slide-hammer weight supported by a quadrapod and powered by a motorized cathead. A reverse motion of the slide-hammer was used to retrieve the split spoon.

The sample was transferred to the sample staging area located about 20 to 50 ft from the pond cells. This procedure minimized the length of time workers were exposed to the higher radiation levels in the pond cells. The staging area contained tables covered with plastic and was surrounded by a wind screen to minimize wind blown dust. In the staging area, split spoons were opened, sediments were described, field notes were recorded, and samples were composited and transferred to the proper sample containers. As many sampling activities as possible were conducted away from the ponds to reduce radiation exposure.

The hole left by the removal of the split spoon was not expected to remain open, so a plug (boulder buster) was attached to the drive rod, measured to extend just beyond the end of the casing, and inserted into the casing. The casing was attached to the connecting piece on the slide, and the slide-hammer was used to drive the mechanism another 2 ft into the coarse dense soil and gravel. The plug was removed, a split spoon attached to the drive rod and driven another 2 ft to collect the next sample. This sequence of events was repeated until all the samples were collected at a sampling location.

To seal the boring after sampling, granular bentonite was poured into the casing and hydrated with distilled water to prevent subsequent alteration of the distribution of pond contaminants during continued use of the pond. The upper section of the casing was removed to free the boat.

The 0 to 2 ft layer of cell 1964 (which was dry during sampling) was sampled using a split spoon attached to a jackhammer driven by a compressor. Below the 2-ft level, the gravel soil was so dense and solid, the equipment repeatedly failed, so the slide-hammer mechanism mounted on a tripod was used to collect the remaining samples. The same sequence of events as was used in the wet pond cells was utilized, that is, drive casing, remove the boulder buster, drive the split spoon inside the casing to collect the sample, remove the split spoon, take the split spoon to a staging area to open it, composite and package the sampling, and decontaminate the split spoon. Plywood was used as a sampling platform to

help control contamination and dust during sampling. The borings were also sealed using granular bentonite and hydrating it with distilled water.

All of the samples were analyzed on-site in the EG&G laboratory for hexavalent chromium, due to a 24-hr holding time. Some samples were transferred to EG&G personnel for radiation and treatability tests. All of the remaining samples were shipped to the Envirodyne Engineers Inc. St. Louis laboratory for specific inorganic and organic analysis.

All field and laboratory analysis were performed using EPA approved methods. The TCLP method used is described in 40 CFR, Part 268, Appendix I.

The TCLP was performed on two selected representative sludge and/or core samples collected from each cell of the TRA Warm Waste Pond. TCLP is designed to determine the mobility of both organic and inorganic contaminants present in liquid, solid, and multiphase waste.

One of the samples was used for preliminary TCLP evaluations, to include a percent solid determination, to determine whether the sample contains insignificant solids and is therefore its own extract after filtration, to determine whether the solid portion of the sample requires particle-size reduction, and determine which of the two extraction fluids are to be used for the nonvolatile TCLP extraction of the sample.

The Extraction Procedure Toxicity (EP Tox) Test Procedures are identified in 40 CFR, Part 261, Appendix II. Some of the samples were analyzed by gamma spectroscopy to determine the extent of radionuclide migration. Selected samples of this set (approx. 20%) were also analyzed for isotopic alpha and Sr-90.

Well Drilling/Sampling Procedures. In the Remedial Sampling, Phase I, three wells were drilled adjacent to the Warm Waste Pond. Sediment from each of these wells was sampled at approximately 5 ft intervals, starting

starting at the surface and extending to the shallowest basalt. A sample was collected at the sediment basalt interface. After drilling and sampling, the holes were completed with stainless steel casing. Based on an average thickness of surficial sediment of 50 ft, this strategy yielded approximately 11 samples from each of 3 holes. The holes were completed as monitoring wells.

To determine the sampling locations of the three auger holes adjacent to the Warm Waste Pond, a grid was placed across the 1951, 1957, and 1964 cells. Auger holes were drilled and sampled at three of the intersecting points of the grid.

Boreholes were drilled through a large collection trough which was used to collect the cuttings. Cuttings were transferred to 55-gal drums for storage until analysis is complete, at which time the cuttings will be properly disposed. A stainless steel spoon (2.5 in. or 3 x 24 in.) was driven ahead of the hollow stem auger flight to collect a sample from the 0 to 2-ft interval. With a center plug in place, the augers were advanced to a 5-ft depth and the spoon driven ahead to collect a sample 5 to 7 ft. This procedure was followed until the basalt layer was reached, collecting a 2-ft sample every 5 ft and one from the basalt interface at 50-52 ft. A visual classification of the samples was recorded by a field geologist on a boring log.

The augers were advanced only after the cuttings had been removed and drummed for disposal, thereby minimizing sample cross-contamination.

Little or no drilling fluid (water) was used during construction of wells. Any drilling fluid (water) used to prevent blow-in under saturated conditions was documented. Any water used in drilling, grouting, sealing, purging, well installation, or equipment washing was obtained from TRA or CFA.

General Sampling Procedures. Stainless steel buckets, pans, and spoons were used to composite soil samples by mixing the soil to ensure a representative sample. The volatile fraction for analysis was collected before composites the sample, thus minimizing the loss of some volatile organics.

In cases where a field duplicate was collected, the sample was composited (mixed) and additional sample containers were filled. Field duplicates were labeled and analyzed as separate samples. Sample jars used in volatile organic analysis were not cleaned with solvents.

Well Installation. The well casing and screen were lowered to the bottom of the bore hole through the center of the augers. The auger flight was lifted out of the borehole to prevent the well casing from bending or becoming off-center. The augers were removed in small increments as the filter pack and grout were implaced.

A sand or gravel filter pack was placed adjacent to and directly above the well screen. Calcium bentonite was installed with a tremie pipe to approximately 3 ft from the ground surface. A concrete surface apron sealed the borehole, and additions were made after settling.

Well Development. The wells were developed using a stainless steel bailer after the annular seal has set for a minimum of 48 hours. Three to five times the volume of standing water in the casing and borehole was removed. Development continued until the sediment thickness remaining in the well was less than 5% of the screen length and the water quality measurements had stabilized. Any liquid produced during development was disposed into the TRA Warm Waste Pond. The purging method, volume, and water quality field measurements (temperature, turbidity, pH, and conductivity) were recorded.

Pathways

Distribution of Contaminants

Contaminants from the Warm Waste Pond are distributed in geologic materials under the pond, in the shallow and deep perched water zones, and in the regional aquifer. The INEL Project Office of the USGS has monitored the perched water zones and the Snake River Plain Aquifer for metallic and radioactive contaminants since the early 1960s. Data from this monitoring have been compiled and are used in this characterization report.

In the summer of 1987, grab samples were collected as part of the Preliminary Investigation from the bottom of the 1952 and 1957 cells of the TRA Warm Waste Pond. These samples were analyzed for 40 CFR 261 Appendix VIII constituents and key contaminants identified for further characterization. In the summer of 1988, a second sampling program was conducted for the Warm Waste Pond for the Remedial Response Investigation. Samples were analyzed for toxic metals, radionuclides, and organics from the list of key contaminants identified during the 1987 sampling. Complete results of the 1988 chemical analyses are presented in Rehak (1989).

Contaminants disposed into the Warm Waste Pond could have been distributed in a number of ways:

- Infiltration to the aquifer with subsequent transport downgradient
- Removal from solution by chemical precipitation, sorption, or ion exchange
- Leaching by waste water disposed of in the Warm Waste Pond (with or without oxidation) and remobilization.

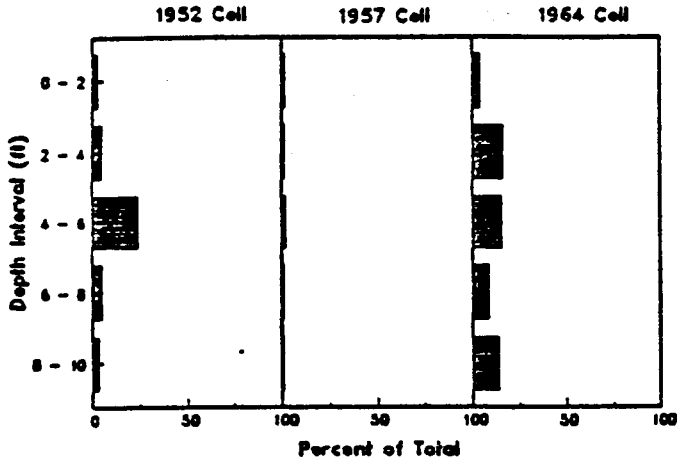
Each of these processes may have been important at different times during the disposal history of the pond or may have played different roles for each of the contaminants. For contaminants that are most affected by the first process, most of the contaminants would have migrated to the aquifer

and would have moved off downgradient within a few years of disposal. If the second process was dominant, then most of the contaminants would be contained somewhere in the geologic materials underneath the Warm Waste Pond. If the third process was significant, the contaminants would originally have been removed from solution, but since then would have gradually been leached from pond sediments. Contaminants would currently be distributed more evenly throughout the entire hydrogeologic system, with low levels of contaminants in water in the perched water zone and in the aquifer.

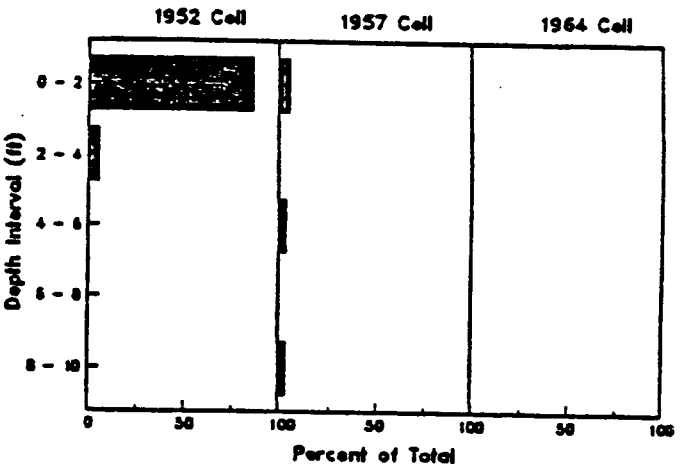
Pond Sediments. Data collected for the Remedial Response Investigation show the distribution of contaminants between cells and depths. This information is valuable for planning remedial actions at the ponds. Figure 26 shows the distribution of toxic metals in pond sediments. In the figure, the percent of the total metal content in each 2 ft interval in each cell is displayed. With the exception of arsenic, at least 50% of the total quantity of the toxic metals is contained in the upper two feet of sediment in the 1952 cell. Approximately two-thirds of the toxic metals are contained in the upper 2 ft of the 1952 and 1957 cells.

All of the samples analyzed for toxic metals were analyzed for total and hexavalent chromium. Hexavalent chromium was below detection in all of these samples. That finding is consistent with the geochemistry of chromium. Hexavalent chromium is mobile and would be transported with the water percolating out of the pond. Therefore, chromium remaining in pond sediments would have been reduced to the trivalent state, the relatively immobile form of chromium.

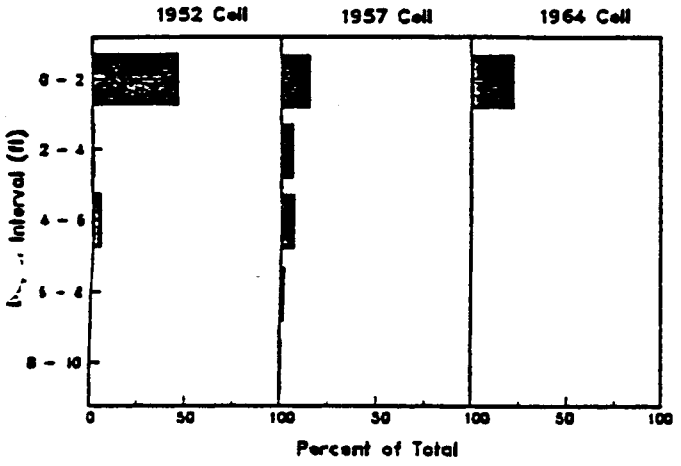
The distribution of most of the other toxic metals in the cells is similar to chromium, with the exception of arsenic, which has a totally different distribution, and in fact seems to be concentrated in the 1964 cell.



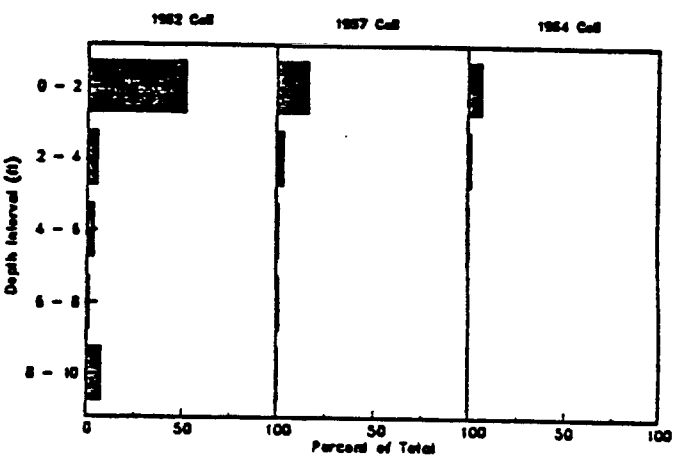
a. Arsenic



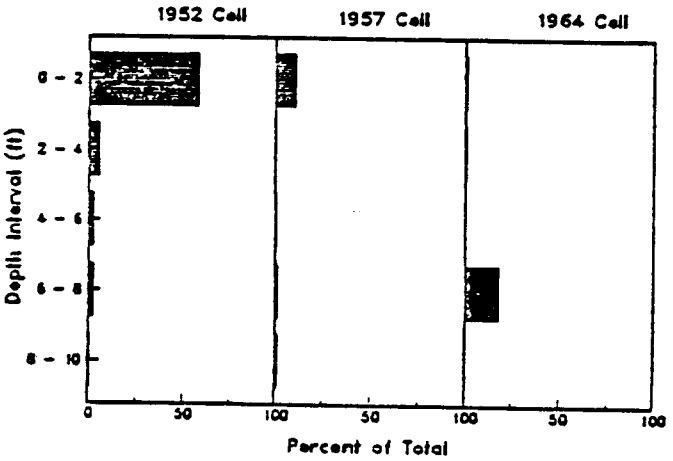
b. Beryllium



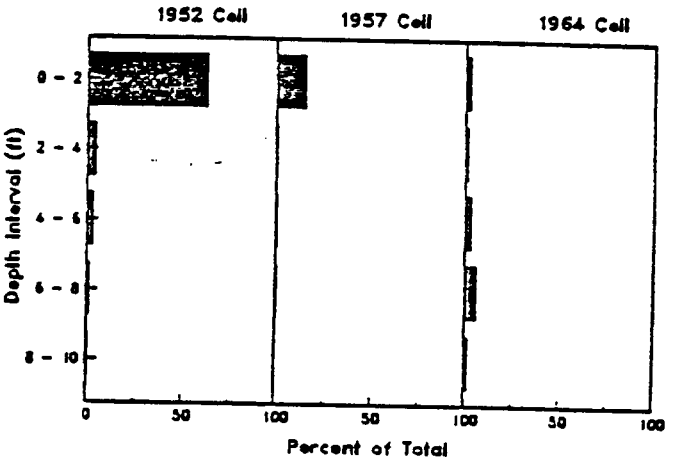
c. Cadmium



d. Chromium



e. Lead



f. Mercury

Figure 26. Distribution of toxic metals with depth and between cells of the TRA Warm Waste Pond.

The average concentration of arsenic in pond sediments is 8.1 mg/kg. Comparing this value to background at other facilities constructed on the Big Lost River Alluvium (Table 10) indicates that arsenic in Warm Waste Pond sediments may only represent background. The relatively uniform distribution with depth in the three cells also supports this conclusion. Therefore, arsenic is probably not a significant contaminant in the pond.

The radionuclides, including the transuranic radionuclides, in pond sediments are somewhat more widespread in their distribution between cells and with depth than the toxic metals. However, the bulk of the radionuclides are contained in the top 4 ft of the pond sediments. Proportionately more radionuclides are present in the 1964 cell than for the toxic metals and chromium. Very little chromium would be expected in the 1964 cell because chromium disposal to the pond ceased in late 1964.

Perched Water Table. There are three primary sources of water for the deep perched water zone: the Chemical Waste Pond, the Warm Waste Pond, and the Cold Waste Pond. Each pond has a unique signature of water chemistry that can be traced in the perched water zone. The Chemical Waste Pond is used to dispose of water high in dissolved solids, but with no radioactivity. The Warm Waste Pond is used to dispose of water containing tritium and other radionuclides. The Cold Waste Pond is used to dispose of water with no radioactivity and low to moderate in dissolved salts. The deep perched water

TABLE 10. BACKGROUND CONCENTRATIONS OF SIX TOXIC METALS AT TRA, NRF, AND CFA AS DETERMINED BY SAMPLING OF SEDIMENTS OUTSIDE FACILITY BOUNDARIES

Metal	Concentration (mg/kg) TRA	NRF	CFA
Arsenic	4.9	8.5	17.8
Beryllium	1.1	U	1.0
Cadmium	1.1	U	U
Chromium	22.7	34.6	27.8
Lead	11.4	18.6	15.3
Mercury	0.1	U	.02

U = Not detected

zone can be divided into three subareas (Figure 27), each fed primarily from one of the ponds, by using the specific conductance (Figure 28) and tritium (Figure 29) distributed in the perched water zone. The subarea high in tritium, fed from the Warm Waste Pond, corresponds to the portion of the deep perched water zone high in chromium (Figure 30).

The effect of the Cold Waste Pond on water chemistry in the deep perched water zone can be seen in the time-series plots of chromium and tritium in some of the perched water wells. Wells USGS-60 and USGS-63 are in the subarea dominated by the Cold Waste Pond; tritium and chromium concentrations in these wells dropped to essentially zero soon after the Cold Waste Pond was put into use in 1982 (Figure 31). Well USGS-70 (Figure 32) shows a more gradual decline in chromium and tritium, but does show that most of the water in well USGS-70 is currently from the Cold Waste Pond. Wells that are in the subarea fed by the Warm Waste Pond show some decline in chromium after the Cold Waste Pond went into use, but continue to show elevated chromium concentrations (Figures 33).

Water in the deep perched water zone contained chromium concentrations in the range of 100 to 200 μg/L in the early 1980s. Those portions of the deep perched water zone recharged by the Cold Waste Pond were flushed of chromium after the Cold Waste Pond was put into service. The rate of flushing depended on proximity to the pond with closer wells being flushed more rapidly. Wells in the portion of the deep perched water zone recharged by the Warm Waste Pond continue to show elevated chromium concentrations.

If chromium is being leached out of the sediments under the Warm Waste Pond, it is generating leachate with concentrations between 100 and 200 μg/L. A calculation was performed to evaluate the effect of leaching chromium from Warm Waste Pond sediments on the amount of chromium remaining in the sediments. To perform the calculation, chromium was added to the pond as given in Table 6. At the same time, chromium was removed from the pond by leaching. Figure 34 shows the cumulative mass of

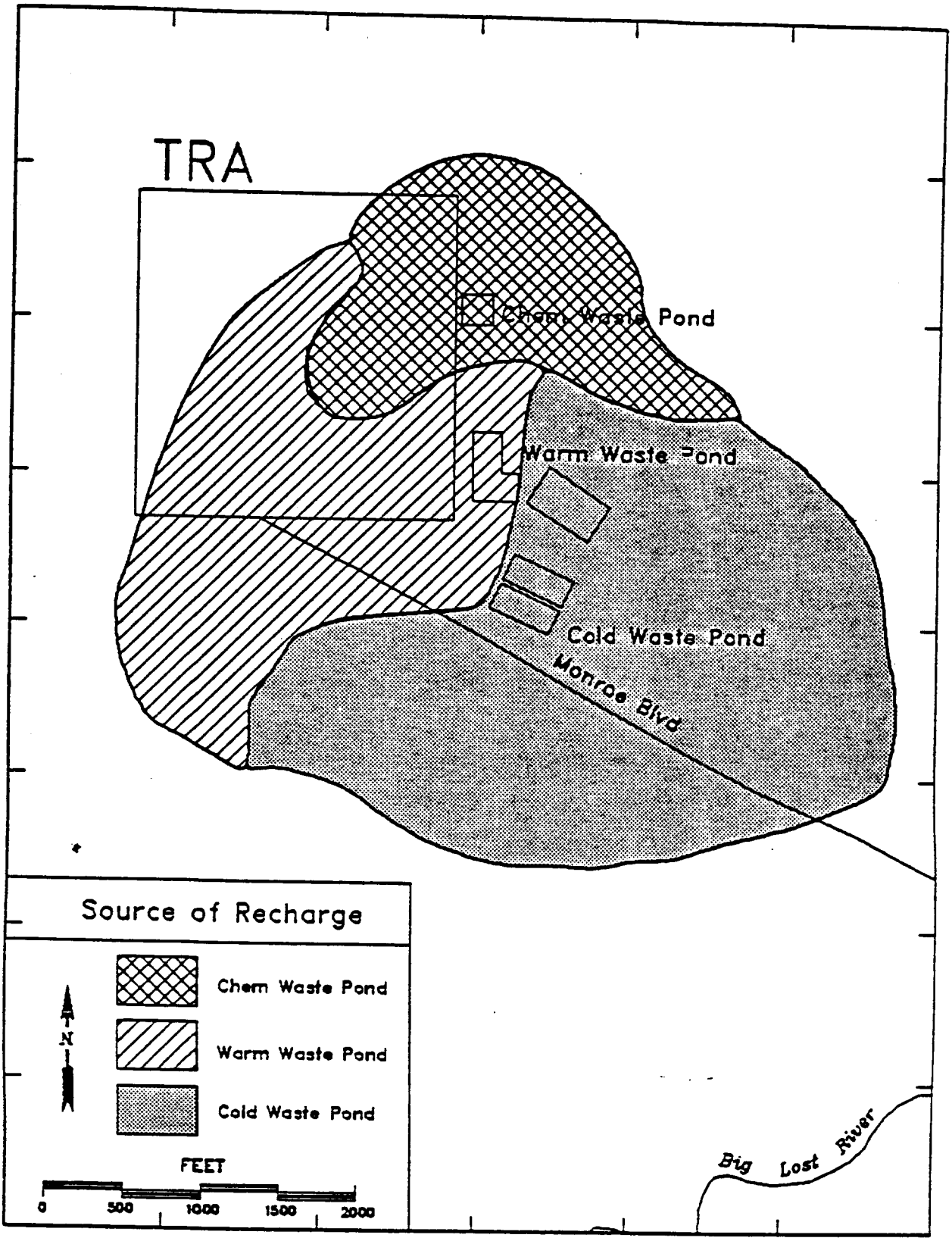


Figure 27. Map showing the three subareas of the deep perched water zone based on the source of recharge to the deep perched water zone, April 1988.

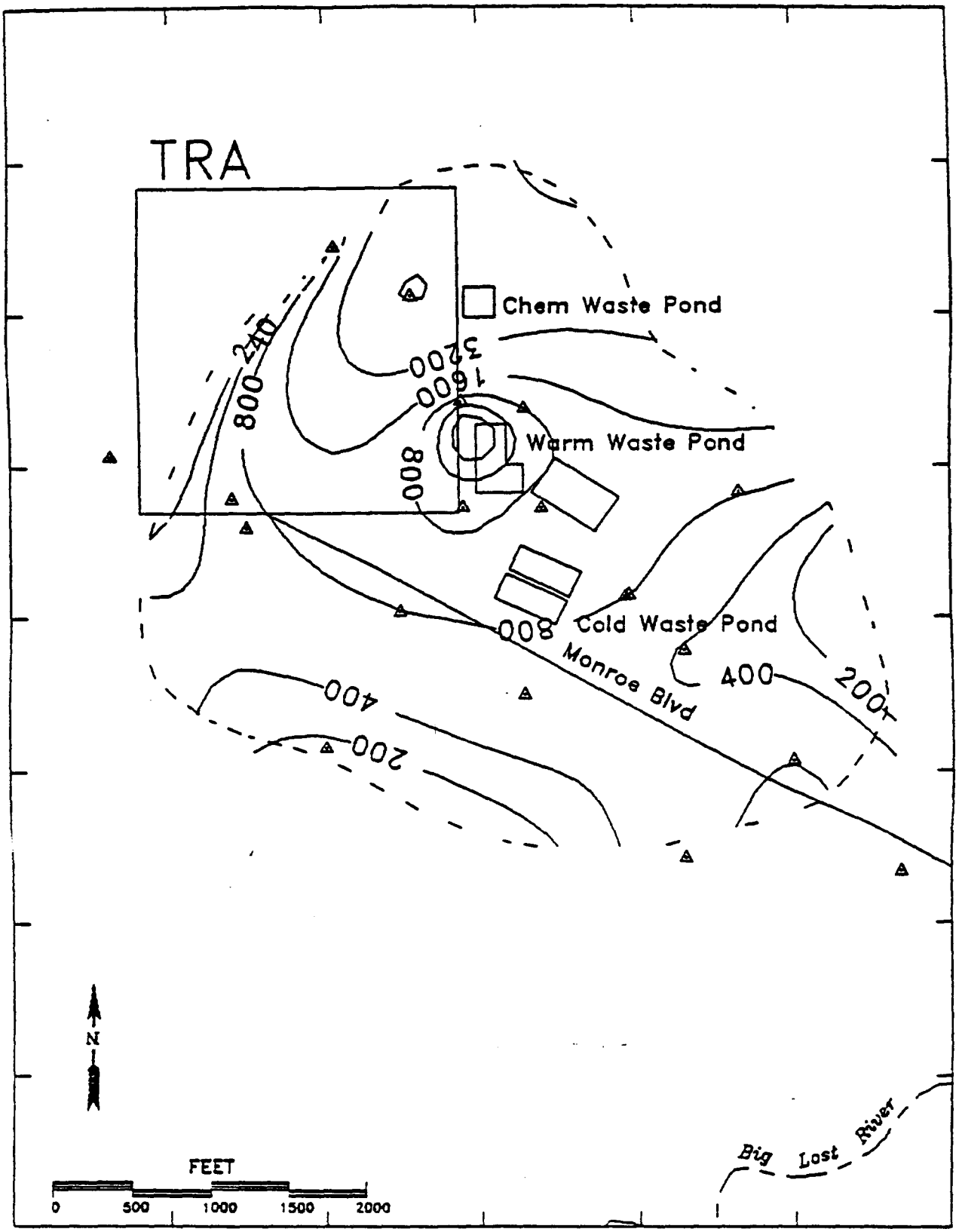


Figure 28. Contour map showing the distribution of specific conductance (micro mhos/cm^2) in the deep perched water zone, April 1988.

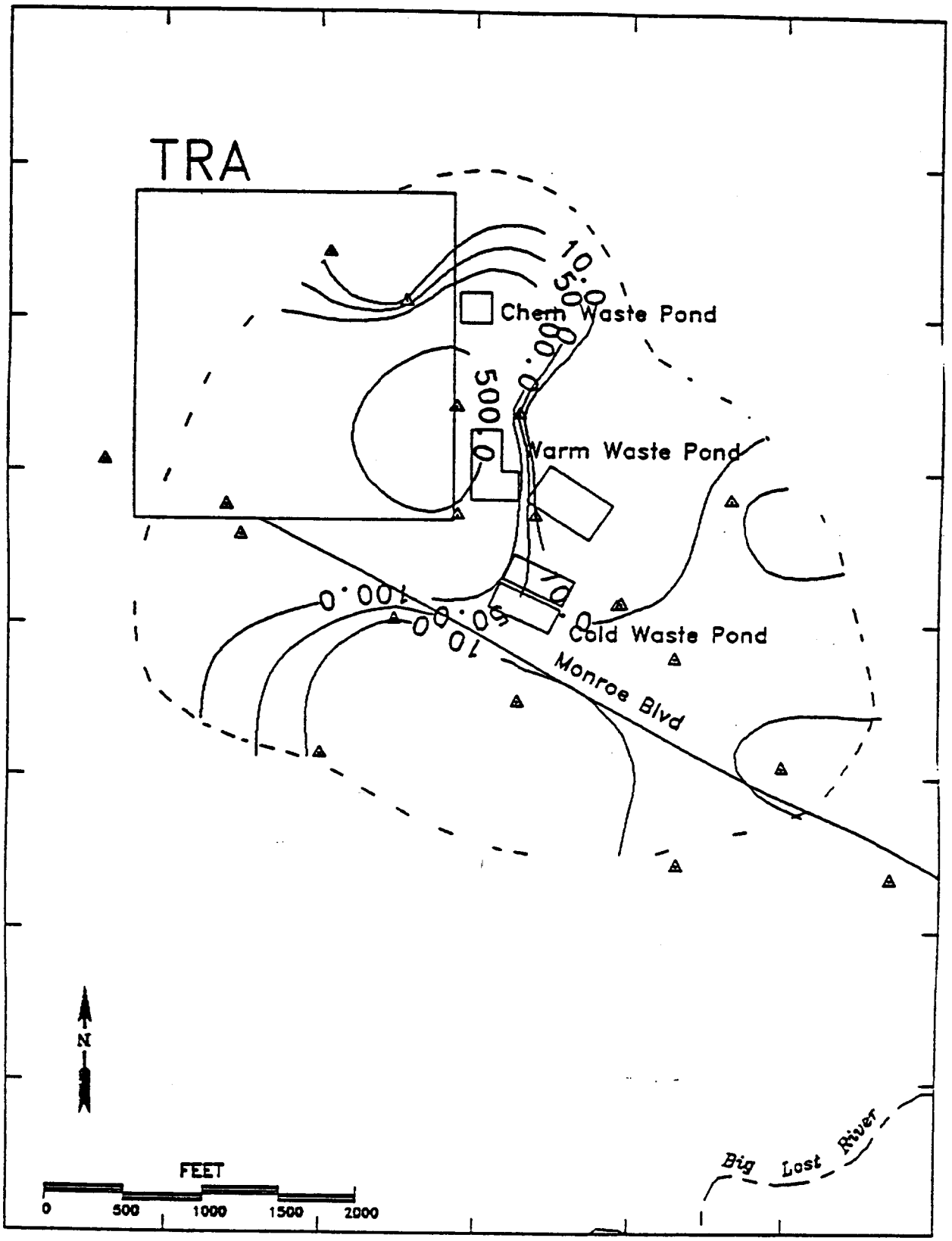


Figure 29. Contour map showing the distribution of tritium (pCi/mL) in the deep perched water zone, April 1988.

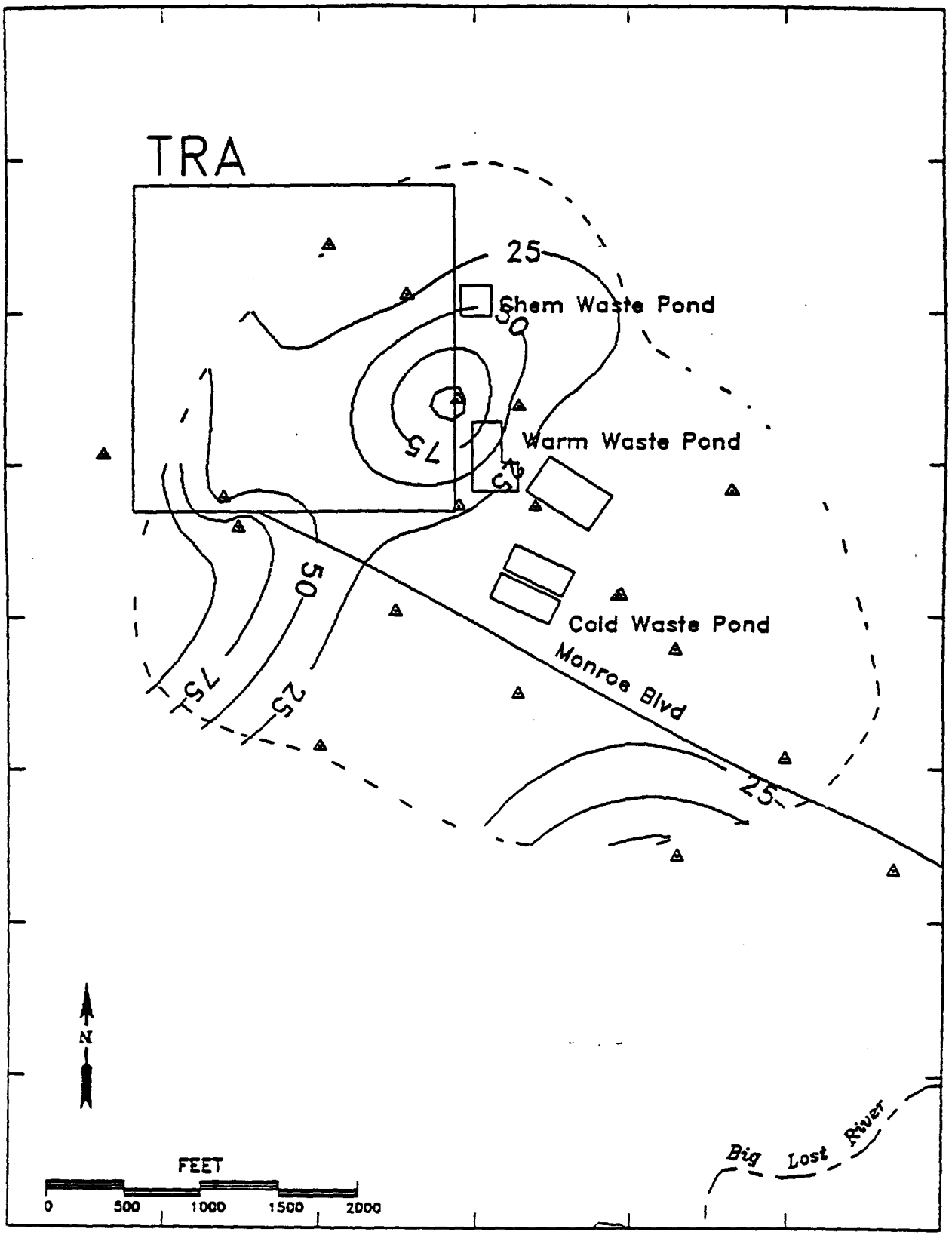
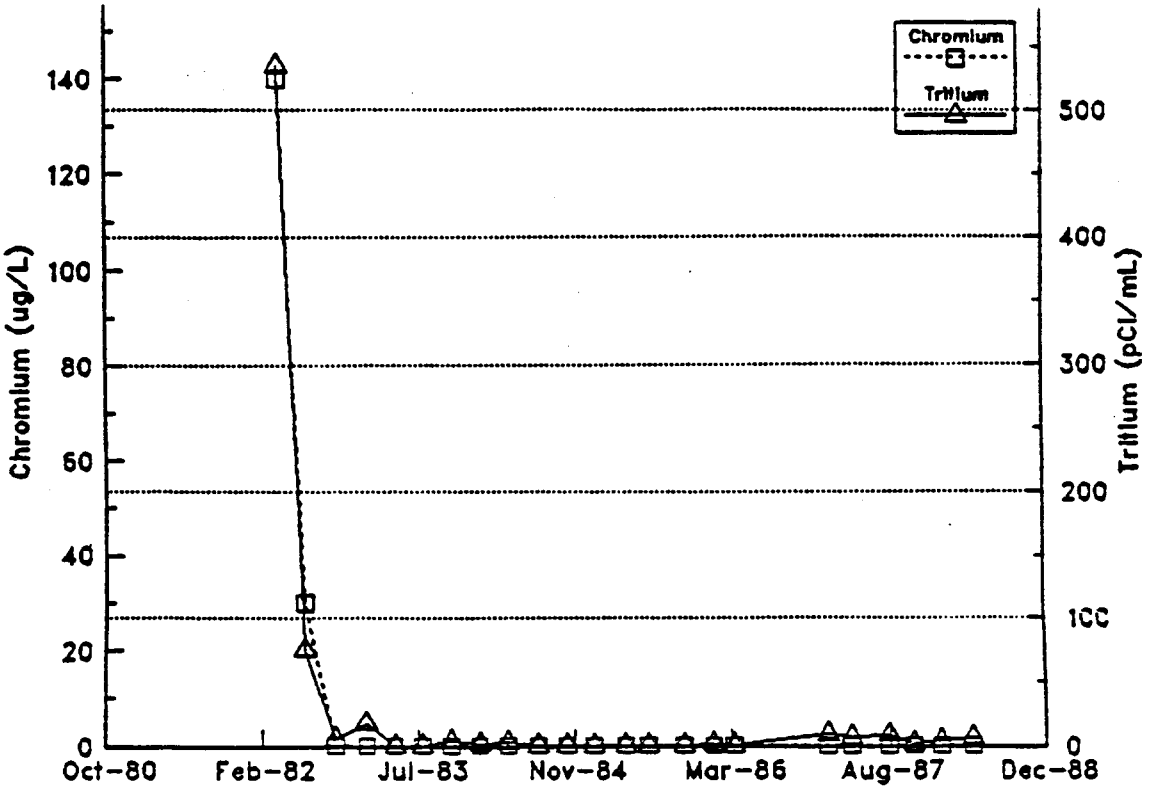
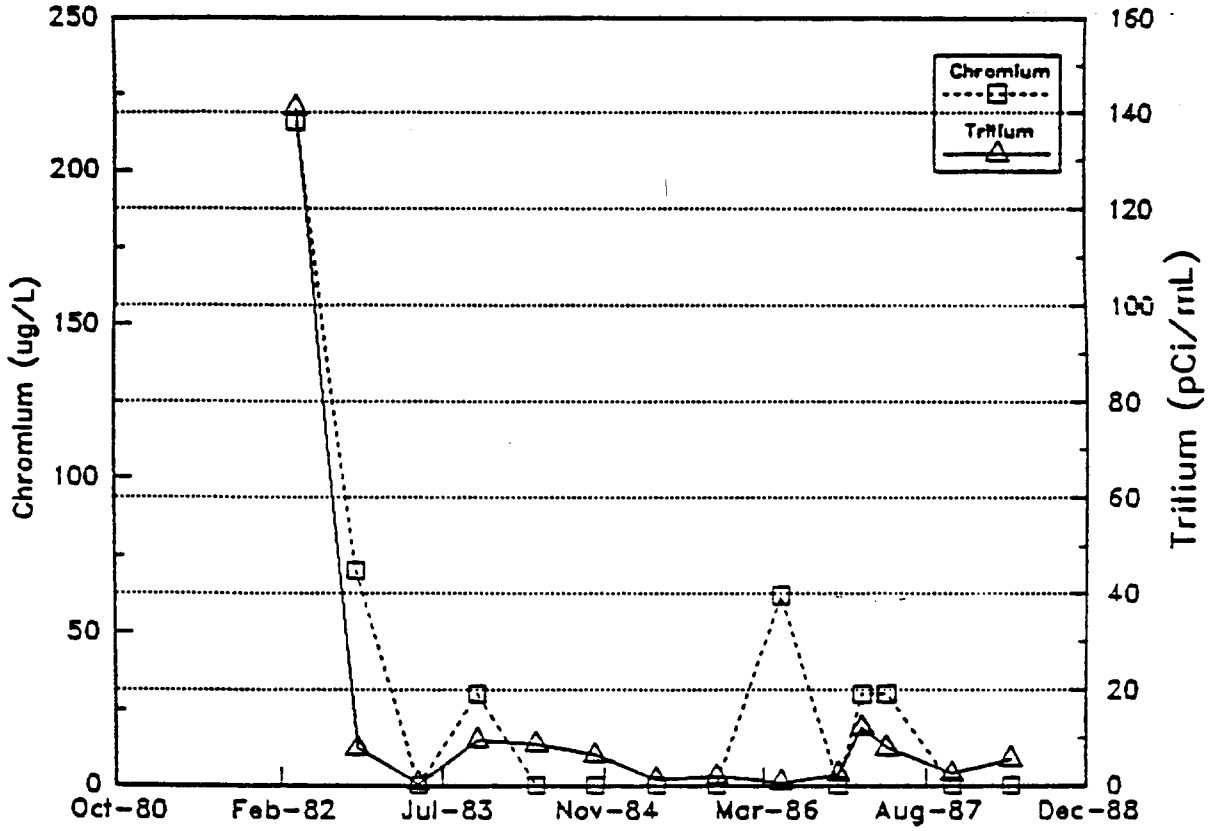


Figure 30. Contour map showing the distribution of chromium (μg/L) in the deep perched water zone, April 1988.



a. USGS-80



b. USGS-63

Figure 31. Tritium and chromium concentrations in wells USGS-60 and USGS-63 which are completed in a portion of the deep perched water zone directly recharged by the Cold Waste Pond.

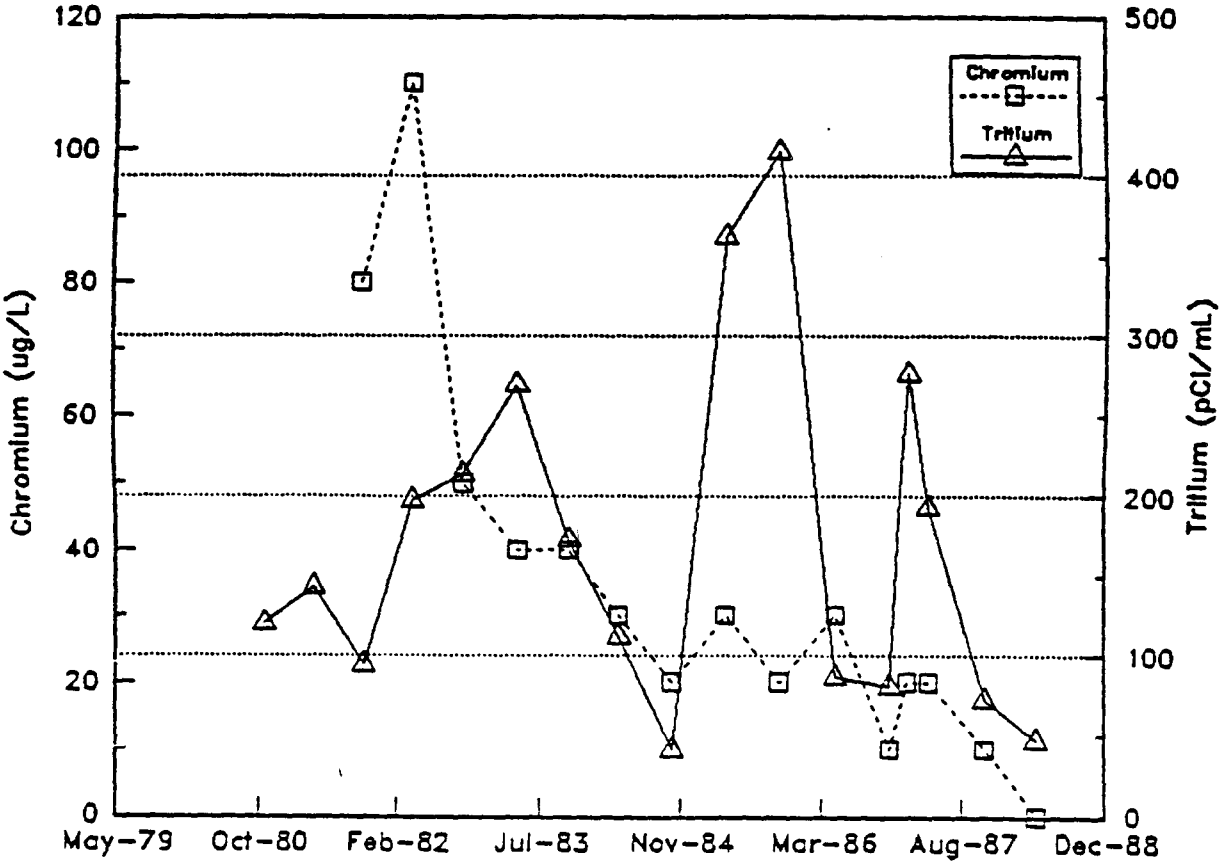


Figure 32. Tritium and chromium concentrations in well USGS-70, located near the margin of the deep perched water zone in an area recharged by the Cold Waste Pond.

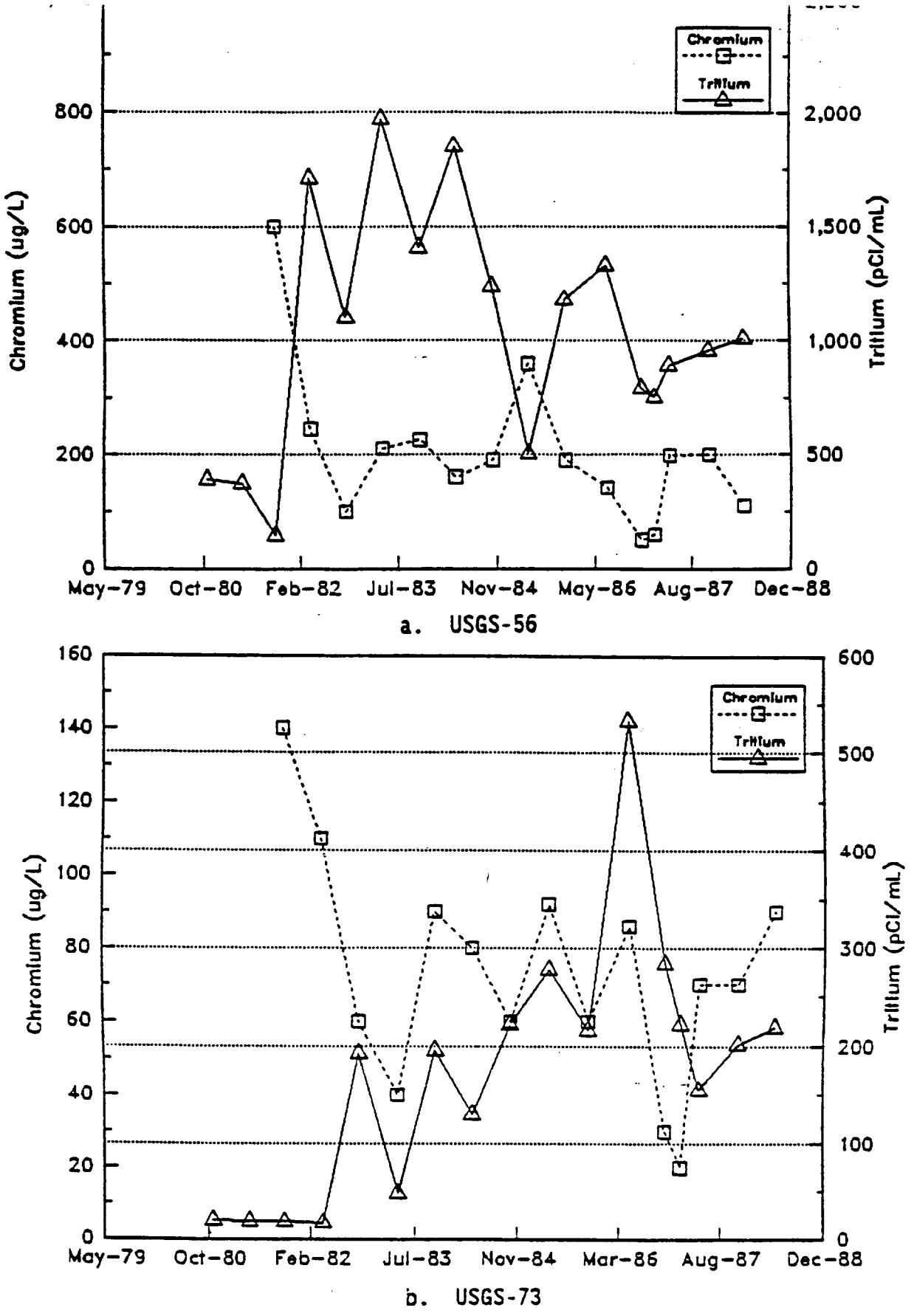


Figure 33. Tritium and chromium concentrations in well USGS-56 and USGS-73, which are completed in a portion of the deep perched water zone recharged by the Warm Waste Pond.

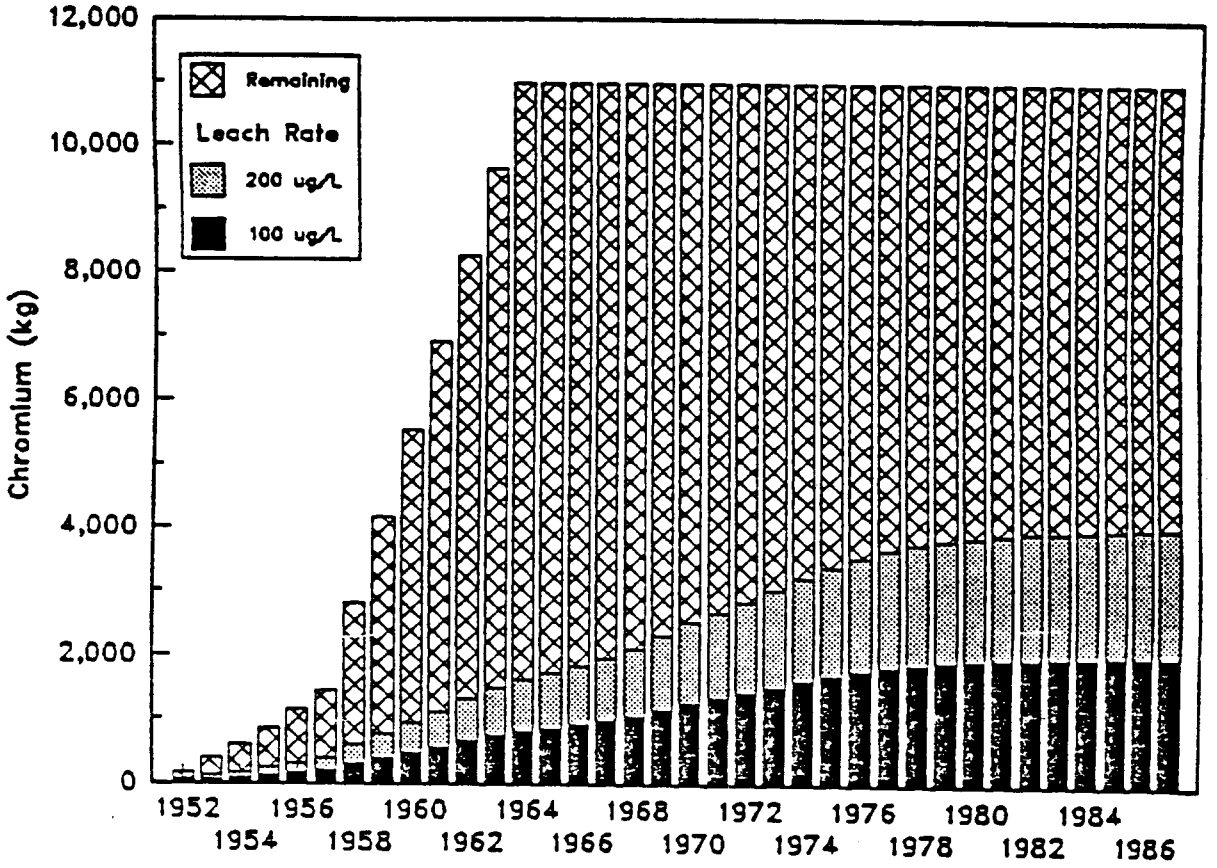


Figure 34. Cumulative discharge of chromium to the TRA Warm Waste Pond and leaching of chromium from pond sediments. Two leachate concentrations are provided to bracket the expected range.

chromium added and removed from Warm Waste Pond sediments as a function of time. Based on a leach rate resulting in 100 μg/L, approximately 2000 kg of chromium would have been removed from pond sediments by 1987. Doubling the final concentration due to leaching leach rate would double the amount removed. The amount of chromium removed from pond sediments at leach rates giving leach rate concentrations between 100 and 200 μg/L would remove more chromium than is missing from the pond sediments based on the mass balance. However, in view of the many uncertainties in the mass balance calculation, leach rates in the indicated range are quite feasible. Therefore, it is possible that some leaching of chromium from pond sediments is continuing. The leach rate is such that it yields concentrations of chromium in the perched water zone of between 100 and 200 μg/L. This concentration range is from two to four times the maximum drinking water concentration limit.

Chromium is also sporadically detected in the shallow perched water zone. Occasionally, samples from auger hole A77, sampled semiannually for water chemistry, have had chromium concentrations above drinking water standards (Figure 35). Water monitored at well A77 is likely from the leak in the retention basin, and not from the Warm Waste Pond. Since the water in the retention basin does not contain chromium, the source of this chromium is unknown.

Regional Aquifer. Chromium in the hexavalent form was disposed to the Warm Waste Pond for the thirteen year period from 1952 until November 1964. Additional hexavalent chromium was injected directly into the Snake River Plain Aquifer for an 8 yr period between November 1964 and September 1972. The chromium could have been distributed in three possible ways in the aquifer. First, because hexavalent chromium is very mobile, it could have moved downgradient with the groundwater. As it moved, it would have been dispersed and diluted. Based on an aquifer flow velocity of 4.5 ft/day, this chromium would have moved some 6 to 12 miles downgradient by 1989. Second, some of the hexavalent chromium could have been reduced to trivalent chromium in the aquifer and precipitated as a solid phase.

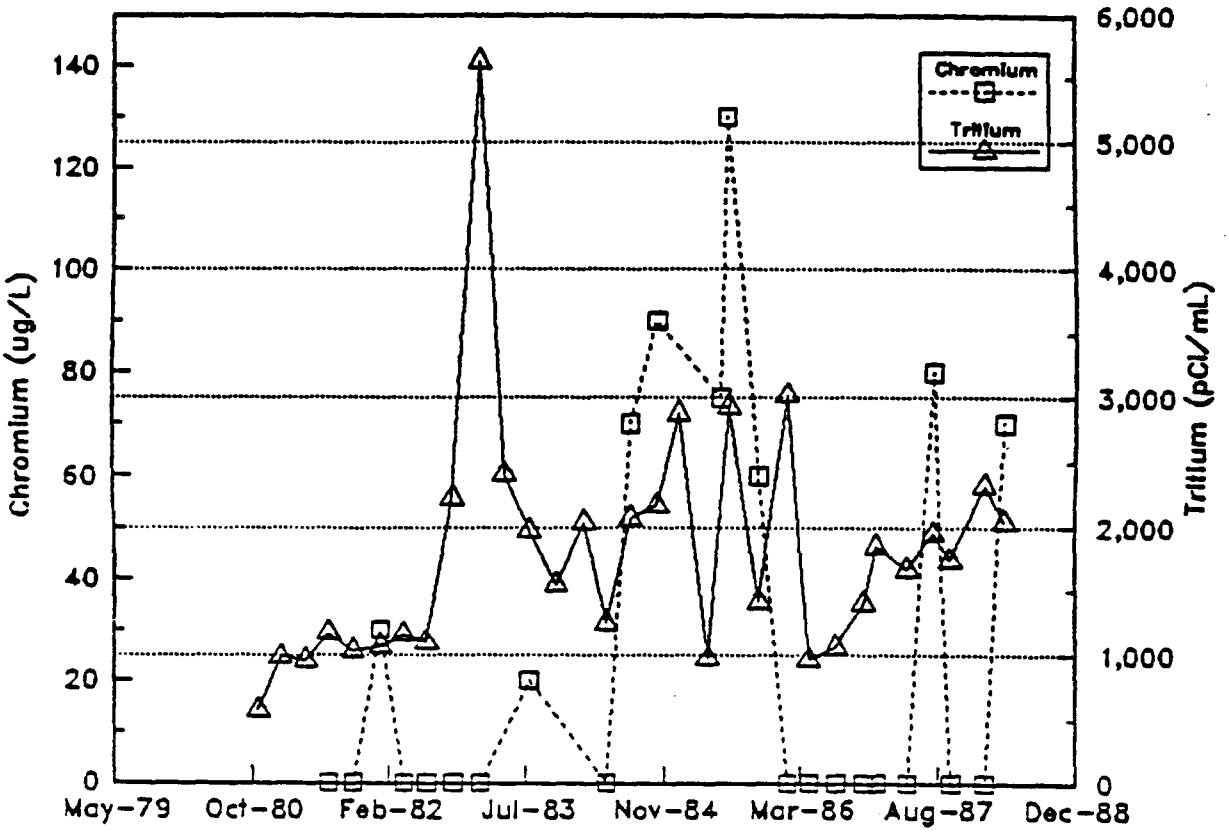


Figure 35. Concentration of chromium and tritium as a function of time in well A77 completed in the surficial alluvium near the retention basin.

Third, some of the chromium may have entered the aquifer through the lower perforations in the Disposal Well. Because of the lower permeability at these greater depths, this chromium may not have migrated very far and may still be in the deeper zones.

There is evidence that most of the chromium remained in the hexavalent state once it reached the aquifer. Table 11 shows results of hexavalent chromium, total chromium, and dissolved chromium analyses done on samples from the aquifer. On the average, hexavalent chromium is 89% of the total or dissolved chromium measured in the aquifer. Considering the extremely low solubility of trivalent chromium, it is likely that most chromium detected moving in the aquifer would be in the hexavalent state.

There is evidence that chromium from the Warm Waste Pond entered the aquifer prior to start-up of the Disposal Well. Regular monitoring of the aquifer for chromium did not begin until 1966, after the Disposal Well was put into use. However, a few water samples collected prior to 1966 were analyzed for chromium. These values indicate a chromium concentration of 200 μg/L in well USGS-65 in 1963. Also, chromium was found far downgradient from the Disposal Well when monitoring began in 1966. Figure 36 is a copy of a map from a USGS report (Barraclough and others, 1967b) showing the distribution of chromium in the aquifer in November 1966. The plume had moved some 15,000 ft downgradient from TRA. The groundwater would have to be moving at a rate of 20 ft/day to reach a distance of 15,000 ft in the 2 yr from November 1964 to November 1966. This is near the upper boundary of flow velocities measured in the aquifer, and so is not impossible. However, distances over which velocities such as 20 ft/day were measured are on the order of 1000 to 3500 ft (Barraclough, and others, 1967b). A more reasonable estimate of transport velocity would be 11 ft/day. Chromium from the Disposal Well would have moved only about 8000 ft in 2 yr at 11 ft/day. Therefore, it is likely that the chromium 15,000 ft downgradient from TRA in 1966 originated in the Warm Waste Pond.

The natural background concentration of chromium in INEL groundwater can be inferred from data collected during a survey of metals in

TABLE 11. PERCENT OF TOTAL OR DISSOLVED CHROMIUM WHICH IS IN THE HEXAVALENT STATE FOR GROUNDWATERS NEAR TRA (unpublished USGS data)

Well	Date	Cr (VI) (µg/L)	Cr (D) (µg/L)	Cr (T) (µg/L)	Cr(VI) (%)
MTR-TEST	12/21/64	6		6	100
MTR-TEST	12/30/65	5		5	100
MTR-TEST	11/01/66	5		4	125
MTR-TEST	04/27/67	5			
MTR-TEST	08/07/67	8			
MTR-TEST	10/27/67	10	10		100
USGS-065	06/21/63	185			
USGS-065	01/06/66	370		410	90
USGS-065	07/28/66	414		419	99
USGS-065	10/31/66	399		405	99
USGS-065	01/31/67	58	58		100
USGS-065	04/30/67	274			
USGS-065	08/07/67	43			
USGS-065	10/27/67	400		400	100
USGS-065	10/29/73	250		430	58
USGS-065	09/06/77	0			
USGS-076	06/21/63	7		11	64
USGS-076	07/15/64	11		14	79
USGS-076	12/21/64	16		18	89
USGS-076	01/06/66	30		25	120
USGS-076	07/28/66	26		26	100
USGS-076	10/31/66	32		33	97
USGS-076	04/30/67	27			
USGS-076	08/07/67	27			
USGS-076	10/27/67	20	30		67
USGS-084	01/07/65	13		16	81
USGS-084	07/20/66	13		18	72
USGS-084	10/27/66	53		54	98
USGS-084	01/31/67	62	63		98
USGS-084	04/27/67	60			
USGS-084	08/03/67	3			
USGS-084	10/26/67	50	60		83
USGS-084	10/25/73	20	70		29
				Avg	89

Cr (VI) - hexavalent
Cr (D) - dissolved
Cr (T) - total

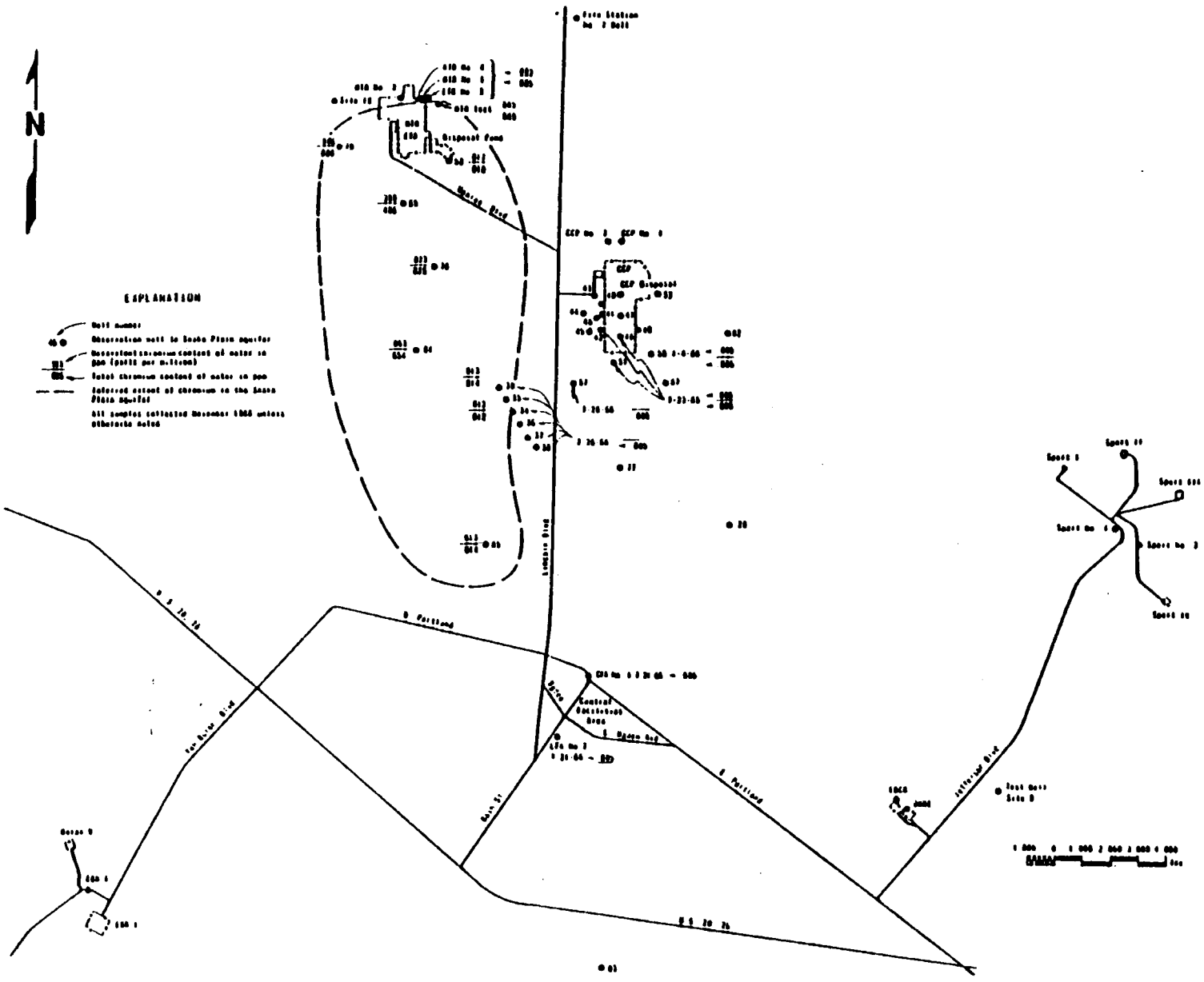


Figure 36. Map of chromium distribution in the Snake River Plain Aquifer, November 1966 (Barraclough and others, 1967b).

groundwater conducted by the USGS (Mann and Knobel, 1988). From data collected in locations upgradient from INEL facilities, the background concentration of chromium is in the range of 2 to 10 μg/L. The distribution of chromium in the aquifer in the fall of 1987 is shown in Figure 37. Of 82 wells sampled for chromium by the USGS, 27 wells had chromium concentrations of 10 μg/L or higher. All of these wells are in the southwest portion of the INEL, mainly just downgradient of TRA, ICPP, and at the RWMC. There is no evidence of widespread contamination across the INEL, nor is there evidence that chromium has migrated as far as the southern INEL boundary.

Chromium concentrations have been monitored in a number of wells downgradient from TRA. Monitoring began in about 1962, so there is only a small amount of data from the period prior to injection. Figure 38 shows chromium and tritium concentrations over time in three downgradient wells (see Figure 10 for well locations). Based on a background concentration of less than 10 μg/L of chromium, all three wells show evidence of chromium contamination. Data from well USGS-65 shows contamination before the injection well was put into service. After the well was put into service in November of 1964, chromium values rose in wells USGS-65 and USGS-76. Well USGS-84 also shows elevated chromium concentrations during the time when injection was occurring.

While concentrations of chromium in groundwater were, at times, above the drinking water limit of 50 μg/L, concentrations have generally dropped below the limit at this time. The exception to this is well USGS-65, which still has chromium at levels around 250 μg/L.

The metals survey conducted by the USGS (Mann and Knobel, 1988) showed that chromium concentrations were below the drinking water standard throughout the southern INEL. The only well above the 50 μg/L drinking water standard was well USGS-65. There is a cluster of wells around the RWMC, which showed elevated levels of chromium (20 to 50 μg/L). The RWMC is approximately 7 miles downgradient from TRA, and it is possible that the chromium detected at the RWMC is from the Disposal Well or the

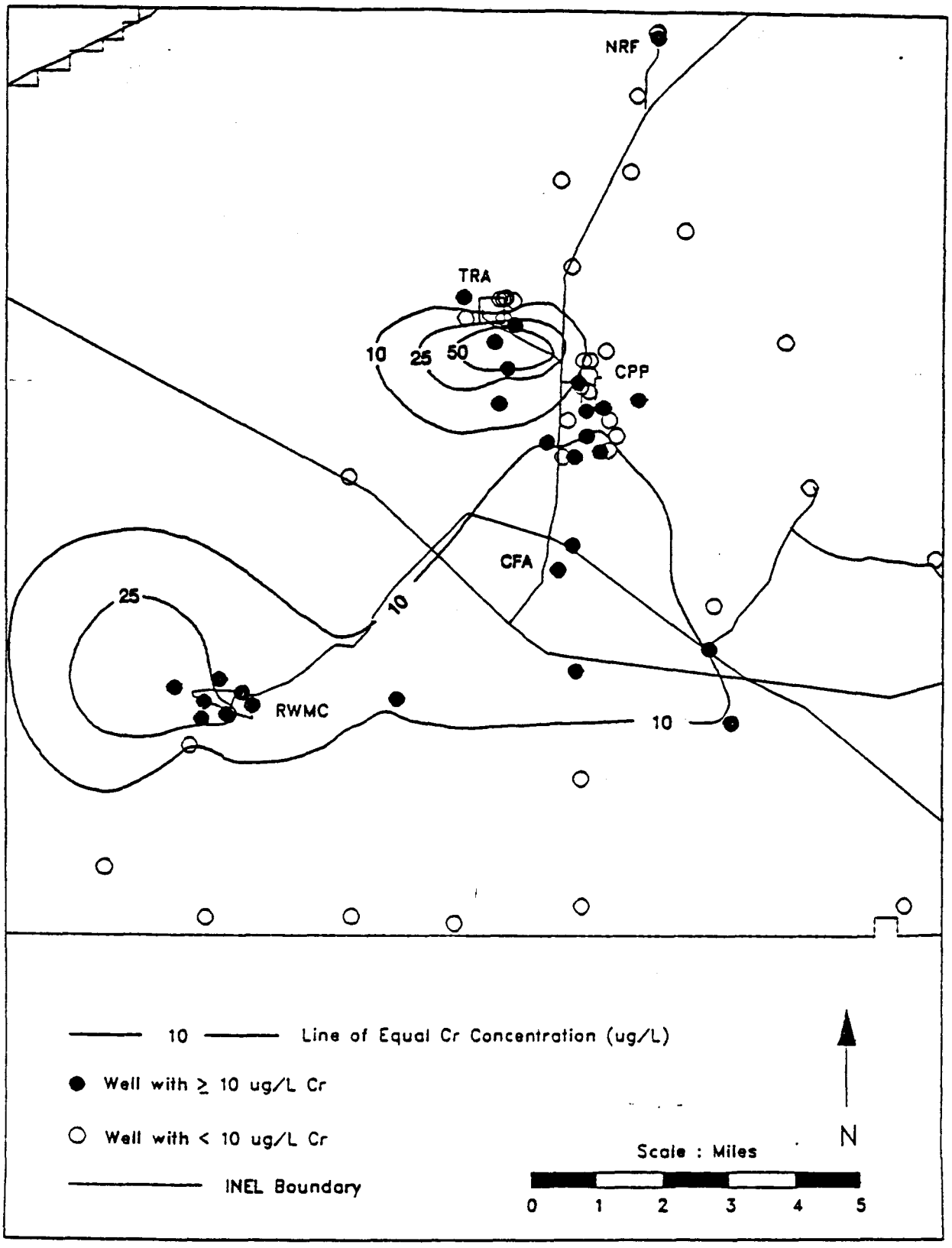
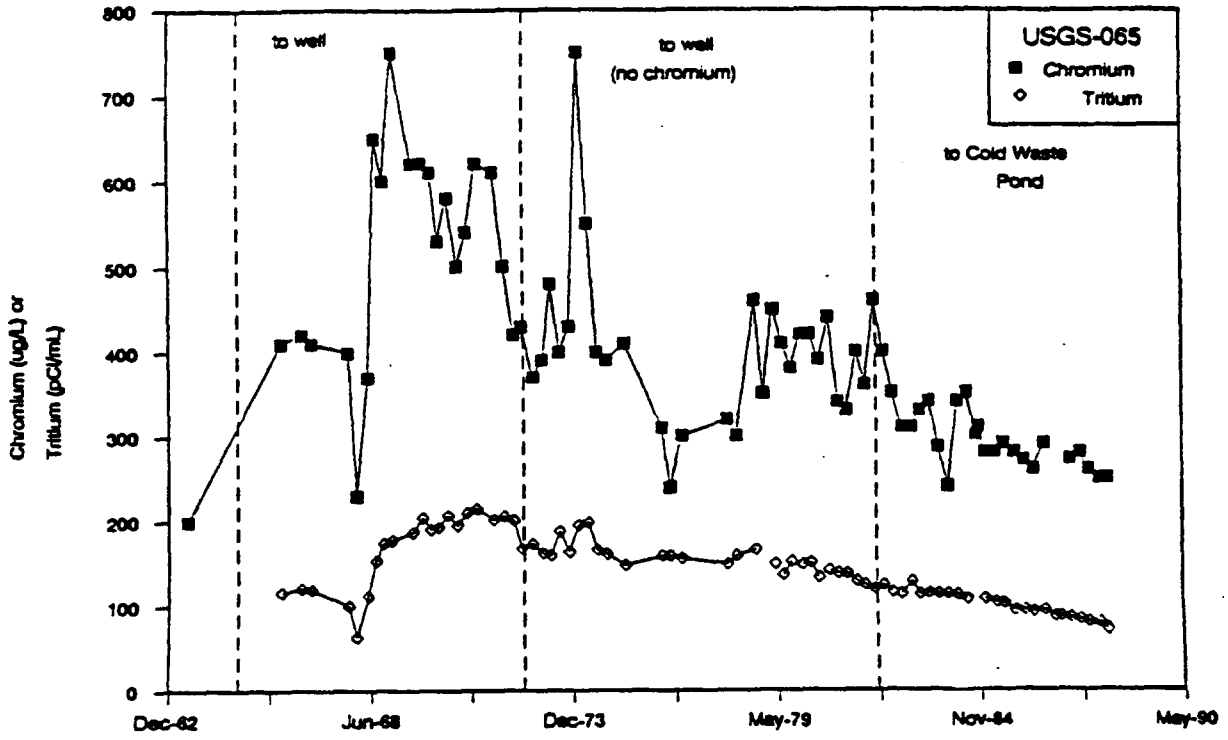
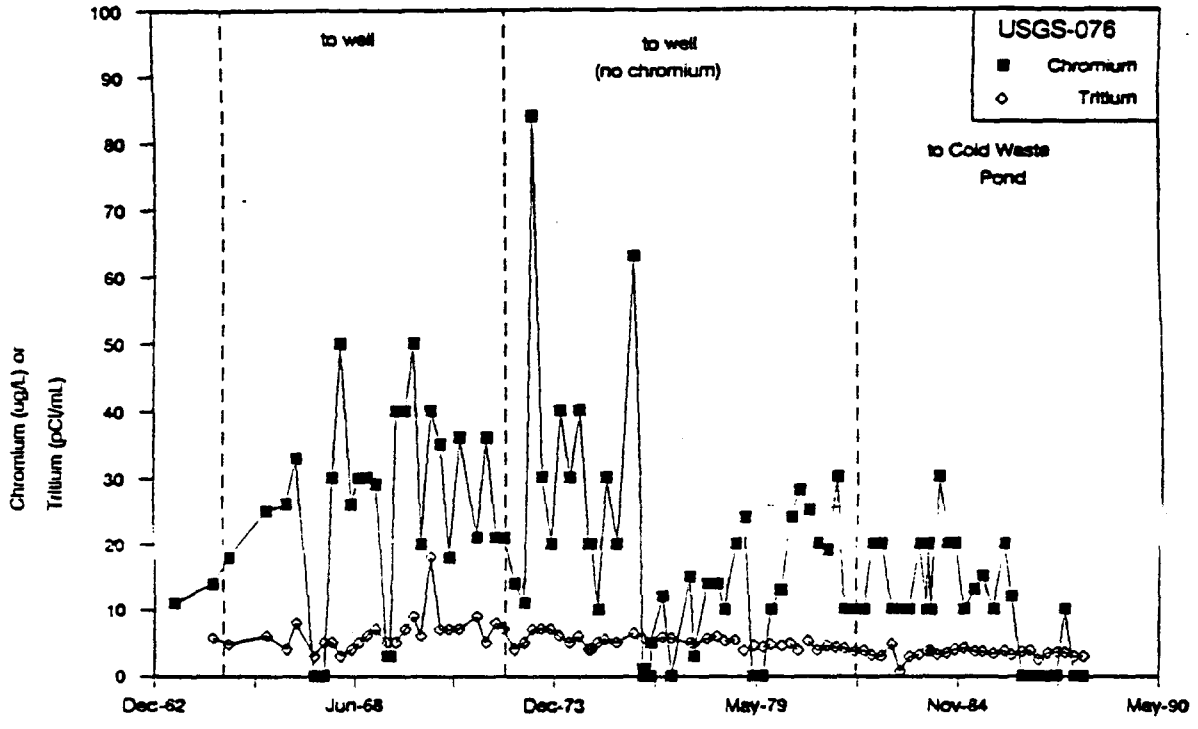


Figure 37. Map of chromium distribution in the Snake River Plain Aquifer, Fall 1987.

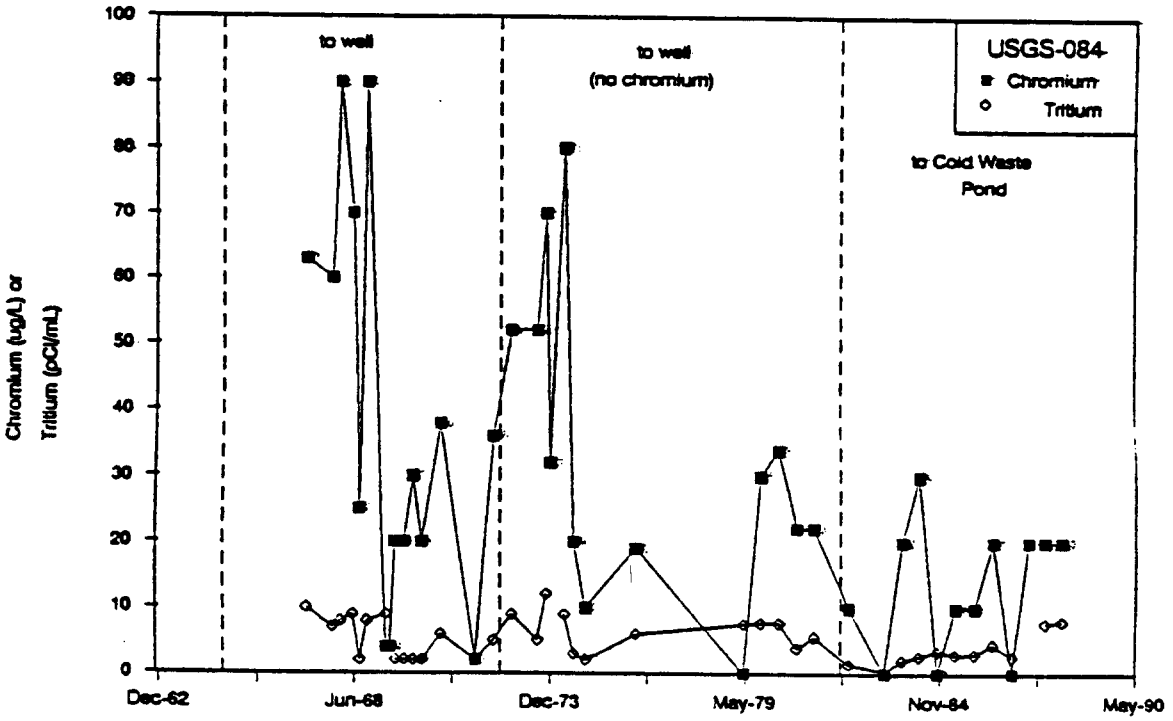


a. USGS-65



b. USGS-76

Figure 38. Chromium and tritium concentrations as a function of time in monitoring wells downgradient from TRA.



c. USGS-84

Figure 38. (continued).

Warm Waste Pond. If the chromium measured at the RWMC is from TRA, it is possible that there are concentrations greater than 50 µg/L in portions of the aquifer near the RWMC that are not currently monitored.

Well USGS-65 has shown very high levels of chromium since 1962. Therefore, it can be concluded that at least some of this chromium was contributed by disposal into the pond. There is, however, a large increase in chromium concentration after the Disposal Well was put into service in 1964. To complicate matters, there is a general parallel behavior between chromium and tritium in the well (Figure 38), with both showing a sharp rise in concentration after June 1968 and a gradual decline since that time. Since tritium and chromium were not associated in their method of disposal after November of 1964, this parallel behavior is not readily explained. The open interval of well USGS-65 is very short, and is at the very top of the aquifer (Figure 12). The well is also completed just above a sedimentary layer, which may have a lower permeability than the surrounding basalts. The most likely explanation for the continued high concentrations of chromium and tritium in well USGS-65 is hydraulic isolation from the rest of the aquifer. The exact nature of this isolation is not well understood.

Mass Balance

To assess the potential for migration of chromium and radioactive contaminants and to obtain a preliminary estimate of the extent to which chromium and radioactive contaminants have migrated from the pond, the amount of contaminants currently present in the Warm Waste Pond sediments and aquifer can be compared to the quantities of wastes disposed to the pond and Disposal Well. Because the quantities of toxic metals other than chromium discharged to the pond are not known, a mass balance cannot be calculated for them. The distribution of these other metals in pond sediments has been discussed in the section on distribution of contaminants. Knowledge of the retention and distribution of the contaminants provides valuable information for planning remedial activities.

The quantities of chromium discharged to the Warm Waste Pond and Disposal Well have been estimated using records and log books that describe past operating practices. Data in the log books indicate the volumes of water passed through the cooling water systems and the concentrations of hexavalent chromium that were maintained in those systems. Based on calculations using those data, a total of approximately 11,000 kg of chromium was disposed to the Warm Waste Pond and 14,000 kg to the Disposal Well (Table 6). Quantities of radionuclides discharged to the pond have been carefully monitored since 1961. Prior to that date, less detailed records were maintained. Estimates of the total curies of selected radionuclides disposed to the pond are shown in Table 7.

The quantities of chromium and radionuclides currently present in pond sediments were calculated from the data collected during the Remedial Response Investigation in 1988. Samples were collected at six locations in each of the three cells of the Warm Waste Pond. At each location, samples were collected over five depth intervals: 0-2 ft; 2-4 ft; 4-6 ft; 6-8 ft; and 8-10 ft. To perform the calculations, the following assumptions were made:

- Each sample represented one-sixth the area of the cell from which it was collected. For the the 1952 cell this was 6250 ft^2; for the 1957 cell it was 4792 ft^2; and for the 1964 cell, 16,667 ft^2.

- Each sample was representative of the 2 ft interval over which it was collected.

- The bulk density of the sediments is 1.80 gm/cm^3, which is the average of the values reported for surficial alluvium at the Warm Waste Pond in Table 2.

- The background concentration of the toxic metals in pond sediments (i.e. the naturally occurring levels) are equal to the average background concentration as determined by sampling outside the TRA fence. Background concentrations are given in Table 10.

Table 12 shows the masses of six toxic metals measured in samples from the Warm Waste Pond sediments. Quantities of toxic metals range from minor (beryllium) to very significant (chromium). As the table indicates, the greatest quantities of chromium occur in the cells used the longest (1952) and the lowest amounts are found in the newest cell (1964). The calculated mass of chromium in pond sediments is essentially equal to the quantity disposed into the pond. The uncertainty in the chromium calculation is fairly large, however. A 90% confidence interval for the total amount of chromium in pond sediments is from 4820 to 19,600 kg.

Based on the mass balance calculation for chromium, it can be concluded that a large percentage of the chromium disposed into the Warm Waste Pond remained in the pond sediments. Therefore, there are not likely to be significant quantities of chromium in deeper sediments or basalts.

The curies of selected radionuclides in pond sediments were also calculated (Table 13). Radionuclides were not analyzed as systematically as the toxic metals, and so the calculations are less exact. In most cases, only one sample per pond was analyzed for the 2 to 4 ft depth and one for the 6 to 8 ft depth. Therefore, the single sample collected at a depth has been used as representative of that respective level for the entire pond.

For the radionuclides, radioactive decay since the time of disposal must be considered to determine the balance between disposal and current inventory. For Cr-51, all of the past inventory has decayed, and the current quantity in pond sediments reflects only what has been disposed in the past year. The value of 5.1 Ci compares favorably with the 8 Ci disposed in 1987.

Co-60 and Cs-137 show much higher current inventories in pond sediments than should be there based on estimated discharges to the pond. To account for the difference, a very large number of curies of these two isotopes must have been discharged to the pond in the first few years of

TABLE 12. MASSES OF TOXIC METALS IN WARM WASTE POND SEDIMENTS

Cell	from (ft)	to (ft)	Arsenic (Kg)	Arsenic (%)	Beryllium (Kg)	Beryllium (%)	Cadmium (Kg)	Cadmium (%)	Chromium (Kg)	Chromium (%)	Mercury (Kg)	Mercury (%)	Lead (Kg)	Lead (%)
1952	0	2	5.6	2.0%	3.2	85.5%	7.8	45.2%	6167.7	51.9%	39.9	63.0%	216.8	58.2%
1952	2	4	12.8	4.5%	0.2	5.1%	0.2	1.1%	609.3	5.1%	2.4	3.8%	18.7	5.0%
1952	4	6	68.6	23.9%	0.0	0.0%	0.7	4.1%	404.7	3.4%	1.7	2.6%	8.4	2.3%
1952	6	8	12.8	4.5%	0.0	0.0%	0.0	0.0%	100.7	0.8%	0.8	1.3%	7.8	2.1%
1952	8	10	7.8	2.7%	0.0	0.0%	0.0	0.0%	878.0	7.4%	0.2	0.3%	0.7	0.2%
Subtotal			107.7	37.5%	3.4	90.6%	8.7	50.4%	8160.4	68.7%	44.9	71.0%	252.4	67.8%
1957	0	2	4.0	1.4%	0.2	4.0%	2.5	14.5%	1899.2	16.0%	9.6	15.2%	39.2	10.5%
1957	2	4	3.3	1.2%	0.0	0.0%	0.9	5.4%	389.0	3.3%	0.4	0.6%	0.5	0.1%
1957	4	6	5.7	2.0%	0.1	2.7%	1.1	6.3%	138.9	1.2%	0.3	0.4%	2.3	0.6%
1957	6	8	2.3	0.8%	0.0	0.0%	0.2	1.2%	146.2	1.2%	0.1	0.2%	4.5	1.2%
1957	8	10	1.2	0.4%	0.1	2.7%	0.1	0.6%	43.0	0.4%	0.0	0.0%	3.3	0.9%
Subtotal			16.5	5.7%	0.4	9.4%	4.8	27.9%	2616.2	22.0%	10.4	16.4%	49.7	13.3%
1964	0	2	10.5	3.7%	0.0	0.0%	3.7	21.7%	869.4	7.3%	1.4	2.1%	2.7	0.7%
1964	2	4	45.1	15.7%	0.0	0.0%	0.0	0.0%	213.4	1.8%	0.7	1.1%	2.0	0.5%
1964	4	6	44.4	15.5%	0.0	0.0%	0.0	0.0%	15.8	0.1%	1.6	2.4%	0.0	0.0%
1964	6	8	24.1	8.4%	0.0	0.0%	0.0	0.0%	2.7	0.0%	3.4	5.4%	65.6	17.6%
1964	8	10	38.8	13.5%	0.0	0.0%	0.0	0.0%	3.2	0.0%	1.0	1.5%	0.0	0.0%
Subtotal			162.9	56.7%	0.0	0.0%	3.7	21.7%	1104.5	9.3%	8.0	12.6%	70.4	18.9%
Totals			287.0	100.0%	3.7	100.0%	17.2	100.0%	11881.1	100.0%	63.3	100.0%	372.4	100.0%
Disposed (est)									10985.1					
Percent Retained									108.2%					

TABLE 13. TOTAL CURIES OF SELECTED RADIONUCLIDES IN WARM WASTE POND SEDIMENTS

Cell	from (ft)	to (ft)	Cr 51 (Ci)	Cr 51 (%)	Co 60 (Ci)	Co 60 (%)	Cs 134 (Ci)	Cs 134 (%)	Cs 137 (Ci)	Cs 137 (%)	Sr 90 (Ci)	Sr 90 (%)	Number of Samples
1952	0	2	1.4	26.7%	63.9	44.6%	0.4	35.3%	80.3	30.2%	2.4	16.6%	6
1952	2	4	2.0	40.0%	9.7	6.7%	0.1	10.3%	13.7	5.1%	0.8	5.8%	1
1952	4	6	0.2	4.7%	2.0	1.4%	0.0	1.7%	4.5	1.7%	0.1	0.6%	6
1952	6	8	0.8	15.3%	3.4	2.4%	0.0	0.0%	0.5	0.2%	0.7	4.6%	1
1952	8	10	0.6	12.4%	0.3	0.2%	0.0	0.0%	0.2	0.1%	0.7	5.2%	6
Subtotal			5.1	99.1%	79.3	55.4%	0.5	47.3%	99.1	37.3%	4.7	32.8%	
1957	0	2		0.0%	23.5	16.4%	0.2	16.4%	44.9	16.9%	1.2	8.3%	6
1957	2	4		0.0%	1.3	0.9%	0.0	1.0%	1.6	0.6%	0.2	1.4%	5
1957	4	6	0.0	0.4%	1.3	0.9%	0.0	0.9%	1.7	0.6%	0.1	0.6%	6
1957	6	8		0.0%	0.2	0.1%	0.0	0.0%	0.1	0.0%	0.1	0.8%	3
1957	8	10	0.0	0.2%	0.4	0.3%	0.0	0.0%	0.7	0.3%	0.0	0.2%	5
Subtotal			0.0	0.6%	26.6	18.6%	0.2	18.2%	48.9	18.4%	1.6	11.3%	
1964	0	2		0.0%	24.5	17.1%	0.2	18.9%	82.1	30.9%	1.7	11.6%	6
1964	2	4		0.0%	10.6	7.4%	0.2	15.5%	33.3	12.5%	4.4	30.7%	2
1964	4	6		0.0%	1.2	0.8%	0.0	0.0%	1.9	0.7%	0.8	5.3%	6
1964	6	8		0.0%	0.6	0.4%		0.0%	0.3	0.1%	1.0	6.7%	1
1964	8	10	0.0	0.2%	0.4	0.3%	0.0	0.0%	0.2	0.1%	0.2	1.7%	5
Subtotal			0.0	0.2%	37.3	26.0%	0.4	34.4%	117.8	44.3%	8.0	56.0%	
Totals			5.1	100.0%	143.2	100.0%	1.2	100.0%	265.8	100.0%	14.4	100.0%	
Remaining[a]			0.0		26		0.3		110		64		
Total Disposed[b]			12020		470		33		185		101		

a. Total curies of each radionuclide which would currently remain from the amount discharged to the pond after correction for radioactive decay from the time of discharge until 1988, from Table 3.

b. Total curies disposed of to the Warm Waste Pond between 1952 and 1987, from Table 3.

operation before records of discharge were maintained. Only Sr-90 shows a net loss of curies from the pond sediments. Referring to Table 8, strontium is one of the more mobile radioisotopes, and it is likely that some migration of Sr-90 has occurred from the pond. However, because of the large uncertainties associated with the radionuclide inventories, it is impossible to judge how much has been released. Both Co-60 and Sr-90 are present in the deep perched water zone beneath TRA reflecting migration to that depth. Cs-137 has not been detected in the deep perched water zone. Co-60 has also been detected in one well (USGS-65) in the aquifer beneath TRA.

One radionuclide not shown in Table 13 is tritium. Tritium is not retarded by geologic materials, and so it can be concluded that all of the tritium discharged to the pond was released to the subsurface. Without retardation, tritium would move rapidly to the aquifer and be transported downgradient. Based on the estimated discharge of tritium to the Warm Waste Pond (Table 7), a total of about 9400 Ci have been discharged to the pond. Correcting for radioactive decay, there should remain about 3,700 Ci of tritium in the vadose zone beneath the pond and in the Snake River Plain Aquifer from disposal at TRA.

The curies of transuranic elements present in Warm Waste Pond sediments were also measured (Table 14). No inventories of disposed transuranic elements are available for the Warm Waste Pond. Also, fewer samples were analyzed for transuranic elements than for other analyte types because of the high cost of analysis. A maximum of four samples were collected from a single depth interval within a cell; and for many depth intervals, one or no samples were collected. Therefore, no attempt was made to estimate the total number of curies in each layer in each cell. The totals are only for those samples actually analyzed. Total quantities will be higher, but there are insufficient data to evaluate by how much.

The total amount of chromium in the deep perched water zone and in the regional aquifer can be calculated from the data used to generate the contour maps shown in Figures 30 and 37. The areas of the deep perched water zone and the regional aquifer were subdivided into cells and the

TABLE 14. TOTAL CURIES OF SELECTED TRANSURANIC ELEMENTS IN WARM WASTE POND SEDIMENTS

Cell	from (ft)	to (ft)	Am 241 (mCi)	Am 241 (%)	U 232 (mCi)	U 232 (%)	U 234 (mCi)	U 234 (%)	U 238 (mCi)	U 238 (%)	Pu 238 (mCi)	Pu 238 (%)	Pu 239 (mCi)	Pu 239 (%)	Cm 244 (mCi)	Cm 244 (%)	Number of Samples
1952	0	2	43.5	29.3%	174.0	89.1%	16.2	39.0%	3.2	20.7%	48.8	29.9%	106.7	31.8%	36.4	41.0%	3
1952	2	4	26.9	18.2%		0.0%		0.0%		0.0%	16.5	10.1%	59.3	17.7%	10.1	11.4%	1
1952	4	6		0.0%		0.0%		0.0%		0.0%		0.0%		0.0%		0.0%	0
1952	6	8	5.0	3.4%		0.0%		0.0%		0.0%	0.3	0.2%	11.8	3.5%	1.9	2.2%	1
1952	8	10	4.2	2.8%	0.2	0.1%		0.0%		0.0%	2.7	1.6%	8.1	2.4%	3.0	3.4%	3
Subtotal			79.6	53.7%	174.2	89.2%	16.2	39.0%	3.2	20.7%	68.3	41.8%	185.8	55.4%	51.5	58.0%	
1957	0	2	24.8	16.7%	19.0	9.7%	10.2	24.6%	2.7	17.8%	32.5	19.9%	72.9	21.8%	14.6	16.4%	4
1957	2	4		0.0%		0.0%		0.0%		0.0%		0.0%		0.0%		0.0%	0
1957	4	6	0.1	0.1%	0.0	0.0%		0.0%		0.0%	0.0	0.0%	0.2	0.0%	0.1	0.1%	2
1957	6	8		0.0%		0.0%		0.0%		0.0%		0.0%		0.0%		0.0%	0
1957	8	10	0.0	0.0%	0.0	0.0%	0.6	1.5%	0.6	4.1%	0.0	0.0%	0.0	0.0%	0.1	0.1%	2
Subtotal			24.9	16.8%	19.1	9.8%	10.9	26.1%	3.4	21.9%	32.5	19.9%	73.1	21.8%	14.8	16.7%	
1964	0	2	15.6	10.5%	1.4	0.7%	11.7	28.2%	6.0	39.4%	30.5	18.7%	34.1	10.2%	11.1	12.5%	3
1964	2	4	27.5	18.5%	0.7	0.3%		0.0%		0.0%	31.0	19.0%	41.2	12.3%	11.0	12.4%	1
1964	4	6	0.3	0.2%	0.0	0.0%		0.0%		0.0%	0.3	0.2%	0.4	0.1%	0.2	0.2%	1
1964	6	8		0.0%		0.0%		0.0%		0.0%		0.0%		0.0%		0.0%	0
1964	8	10	0.4	0.3%	0.0	0.0%	2.8	6.7%	2.8	18.1%	0.6	0.4%	0.6	0.2%	0.2	0.3%	3
Subtotal			43.8	29.5%	2.1	1.1%	14.5	34.9%	8.8	57.4%	62.4	38.2%	76.3	22.8%	22.5	25.3%	
Totals			148.2	100.0%	195.4	100.0%	41.5	100.0%	15.3	100.0%	163.1	100.0%	335.3	100.0%	88.8	100.0%	

concentration of chromium estimated for each cell. Multiplying the concentration of chromium by the volume of water in each cell gives the total quantity of chromium in each cell. The results from the individual cells were summed to give the total quantity of chromium. The calulations are based on the following assumptions:

- porosity of 10%
- background chromium in the deep perched water zone is 0 μg/L
- background chromium in the Snake River Plain Aquifer is <7 μg/L but is a few μg/L.

To take into account that chromium concentrations of 2 to 5 μg/L were found throughout the INEL (Mann and Knobel, 1988) cells with less than 7 μg/L chromium in the aquifer were assumed to represent natural chromium and were not included in the summation.

The total amount of chromium in the water of the deep perched water zone is about 45 kg. Therefore, the amount of chromium in this zone is minor.

The quantity of chromium in the regional aquifer is estimated to be about 14,000 kg. Chromium in this region of the aquifer would have come from TRA with some possible contribution from NRF (Robertson and others, 1974). The NRF switched to a polyphosphate corrosion inhibitor much earlier than TRA and so the contribution from NRF is likely to be small compared to that from TRA. Assuming all 14,000 kg in the aquifer originated at TRA, the quantity balances very well with the 14,000 kg disposed of into the injection well.

Approximately 25,000 kg of hexavalent chromium were disposed of to the Warm Waste Pond and the TRA Disposal Well between 1952 and 1972 (Table 6). Approximately 11,000 kg were discharged to the pond and 14,000 kg to the Disposal Well. Based on sediment sampling in the pond for the Remedial Response Investigation and sampling of water in the regional aquifer by the

USGS, there are currently about 11,000 kg of chromium in sediments of the Warm Waste Pond and about 14,000 kg of chromium in the regional aquifer. From this general agreement it can be concluded that almost all of the chromium discharged to the Warm Waste Pond remains in the sediments of the ponds. Also, essentially all of the chromium discharged at TRA can be accounted for.

Conceptual model

Based on an analysis of the existing data, a conceptual model has been developed of the movement of water and contaminants associated with the TRA Warm Waste Pond. The conceptual model is a verbal description of the processes which are important for contaminant migration. As such, it serves as a summary of what is known about the Warm Waste Pond and the hydrogeologic system at TRA. Areas of uncertainty are highlighted in the development of the conceptual model, which lead to the identification of tasks needed to complete site characterization.

Movement of Water. Discharge of waste water to the Warm Waste Pond has varied over time. Prior to 1962, all waste water from TRA was discharged to the Warm Waste Pond. In 1962, fluids from the regeneration of water softeners and ion exchange columns were diverted to the Chemical Waste Pond. Discharge to the Chemical Waste Pond has generally been from 10 to 20% of the discharge to the Warm Waste Pond. In 1964, cold waste water was diverted from the Warm Waste Pond to the Disposal Well. The volume of water discharge to the Warm Waste Pond remained fairly constant in spite of this diversion up to 1979. In 1979, the volume of water discharge to the Warm Waste Pond was reduced to about 25% of previous levels. Therefore, no significant changes in input volume of water to the shallow and deep perched water zones occurred until 1979.

In 1982, the Disposal Well was closed down and cold waste water began being discharged to the Cold Waste Pond. The Cold Waste Pond currently receives about 10 times as much water as the Warm Waste Pond. Because of decreases in the volumes of water discharge to the Chemical and Warm Waste Ponds, however, the total volume of water discharge to the vadose zone at

TRA is about equal to levels from the 1960s and 1970s. Discharge volumes to the vadose zone at TRA have remained near 250 to 300 million gal/yr except for a 3 yr period from 1979 to 1981 when discharge volumes were only about 70 million gal/yr.

Some water discharged to the Warm Waste Pond is lost to the surficial alluvium prior to discharge to the pond. This occurs through leaks in the retention basin and through several breaks that have occured in the piping carrying water to the pond. Measurable changes in the shallow perched water zone have been associated with pipe breaks. There is an extension of the shallow perched water zone under the retention basin, monitored by auger hole A77, which indicates sufficient leakage to develop a small perched water zone.

Water discharged to the Warm Waste Pond enters the coarse grained surficial sediments. Points of drainage from the pond have varied over time as parts of the pond have become clogged with algae and chemical precipitates. Water then moves downward through the surficial alluvium to the sediment-basalt interface about 50 ft beneath the surface. This interface is generally a low-permeability layer due to finer grained sediments clogging the openings in the basalt. A very small perched water zone develops on top of the basalt. The water continues to move downwards through the underlying basalts until a second low permeability layer is encountered. Vertical flow rates are on the order of 2 ft/day.

The perching layer which occurs at a depth of about 150 ft is variously described as silt, clay, and basalt with fractures filled with silt and clay. It represents a major impediment to vertical flow. A large perched water zone develops on this perching layer. The perched zone was about 400 acres in size in April of 1988. Water movement in the deep perched water zone is lateral as well as vertical. Lateral spreading continues until sufficient area is covered to transmit the available water. This perched water zone has varied in size over the years. The only major change, however, occurred between 1979 and 1981 when the size of the perched water zone greatly decreased due to decreased discharge into surface ponds. With

increased discharge to surface ponds since 1982, the deep perched water zone has returned to its previous size.

Once through the perching layer, water moves down to recharge the Snake River Plain Aquifer. In the aquifer, flow is to the south-southwest at rates that average about 11 ft/day near TRA and decrease to about 4.5 ft/day to the south and southwest of TRA.

Movement of Contaminants. The chemical composition of water discharged to the pond has also varied over time. Prior to 1962, all waste water from TRA was discharged to the Warm Waste Pond. From 1952 to 1962, therefore, radionuclides, water softener and ion exchange column regeneration fluids, and cooling water containing hexavalent chromium all went to the pond. The regenerating fluids would have been high in dissolved salts (mainly sodium, chloride, and sulfate) and may have had wide fluctuations in pH if solutions were not mixed or neutralized before disposal. In 1962, the regeneration fluids were diverted to the Chemical Waste Pond. Hexavalent chromium was disposed of to the pond from 1952 until November of 1964. The pond is currently used to dispose of water containing radioactive wastes.

During the first short period of operation of the Warm Waste Pond, hexavalent chromium probably passed directly through the pond and downward to the Snake River Plain Aquifer. However, algae grew in the pond, died, and built up a mat of organic matter on the bottom of the pond. Hexavalent chromium is a strong oxidizing agent, and would react with the organic matter and reduce chromium to the trivalent state. Once in the trivalent form, chromium would be precipitated, sorbed, or exchanged on solid surfaces and removed from solution. Most of the chromium discharged to the pond is, therefore, still in pond sediments in the trivalent state. Hexavalent chromium that passed through the pond remained in the hexavalent state and moved with the water as an anion.

Most of the radionuclide and toxic metal contaminants disposed into the pond react rapidly with geologic materials and have been concentrated in the top 2 to 4 ft of sediments beneath the pond. On the order of two-thirds of the contaminants are in the upper 2 ft of sediments.

Disposal of chromium to the Warm Waste Pond ceased in 1964. However, chromium concentrations have remained elevated in the perched water zone. The mechanism for this is most likely oxidation and leaching from the pond sediments by percolating waste water.

Some radioactive contaminants are discharged directly to surficial alluvium through leaks in the retention basin, west of the Warm Waste Pond. Some chromium would also have been discharged to sediments near the sump and retention basin from breaks in the underground pipes. Well A77 shows sporadic chromium concentrations above drinking water standards.

Radioactive contaminants (mainly tritium) and hexavalent chromium, which passed through the perched water zone, eventually reached the Snake River Plain Aquifer. There the contaminants have migrated downgradient for distances of several miles. Chromium contamination in the aquifer was measured about 3 miles downgradient of TRA in November of 1966. Between 1964 and 1972, waste water containing hexavalent chromium was discharged directly to the Snake River Plain Aquifer through the TRA Disposal Well. Much of the chromium in the aquifer downgradient from TRA is from this well.

As the contaminants from the pond and well move downgradient, they are dispersed and concentrations decrease. There is currently no contamination from TRA detected above drinking water standards in the aquifer except for well USGS-65. Wells near the RWMC have elevated chromium concentrations and one well has 50 μg/L chromium in the water. Therefore, it is possible that there are areas in the aquifer downgradient from TRA which have concentrations of chromium above drinking water limits.

Some of the recharge from the Warm Waste Pond entered a part of the aquifer surrounding well USGS-65. Well USGS-65 seems to be hydraulically isolated from the rest of the Snake River Plain Aquifer. There is some movement of water through the aquifer at this well as fresh tritium is being added to the water sampled by the well. Tritium concentrations do not show evidence of radioactive decay as they would if the water at well USGS-65 was stagnant. Measurements of chromium in perched-zone wells that

receive water from the Warm Waste Pond are between 100 and 200 µg/L. Concentrations of chromium in well USGS-65 are higher than this range, but lower than some levels in the perched water zone prior to use of the Cold Waste Pond. Therefore, it is possible that water from the west side of the deep perched water zone is migrating downward and recharging the area sampled by USGS-65. Recharge from the Cold Waste Pond does not recharge this part of the aquifer, since the very high volumes of water discharged to the Cold Waste Pond would have flushed well USGS-65.

Discussion

Geologic cross sections show that the thickness of the perching layer varies under TRA. It is probable that water does not move downward through the perching layer uniformly, but moves through a few zones where the perching layer is thinner or more permeable. There are probably at least two of these zones. One point of concentrated recharge to the west, which carries the bulk of the water from the Warm Waste Pond, and one to the southeast, which carries the bulk of the water from the Cold Waste Pond. This would explain the distinct zones of different water quality in the deep perched water zone and the extension of the zone high in tritium and chromium to the west. The point recharge zone to the west directs recharge to a portion of the aquifer tapped by USGS-65. This zone is relatively isolated from the rest of the aquifer. The isolation is probably due to a sedimentary interbed, seen in cross sections, which is only a few feet below the water table at USGS-65 and dips to the south. The high permeability zone to the southeast diverts recharge from the Cold Waste Pond around the portion of the aquifer tapped by USGS-65.

Figure 39 shows the conceptual model of the TRA area in graphical form. Four sources of contaminants have been identified: Disposal Well; retention basin; pipeline breaks; and the Warm Waste Pond. Contaminants released through the retention basin, leaks, and the pond migrate downward, along with infiltrating water, to the Snake River Plain Aquifer. Hexavalent chromium from the Disposal Well was injected directly into the aquifer. Once in the groundwater, contaminants migrate along this pathway

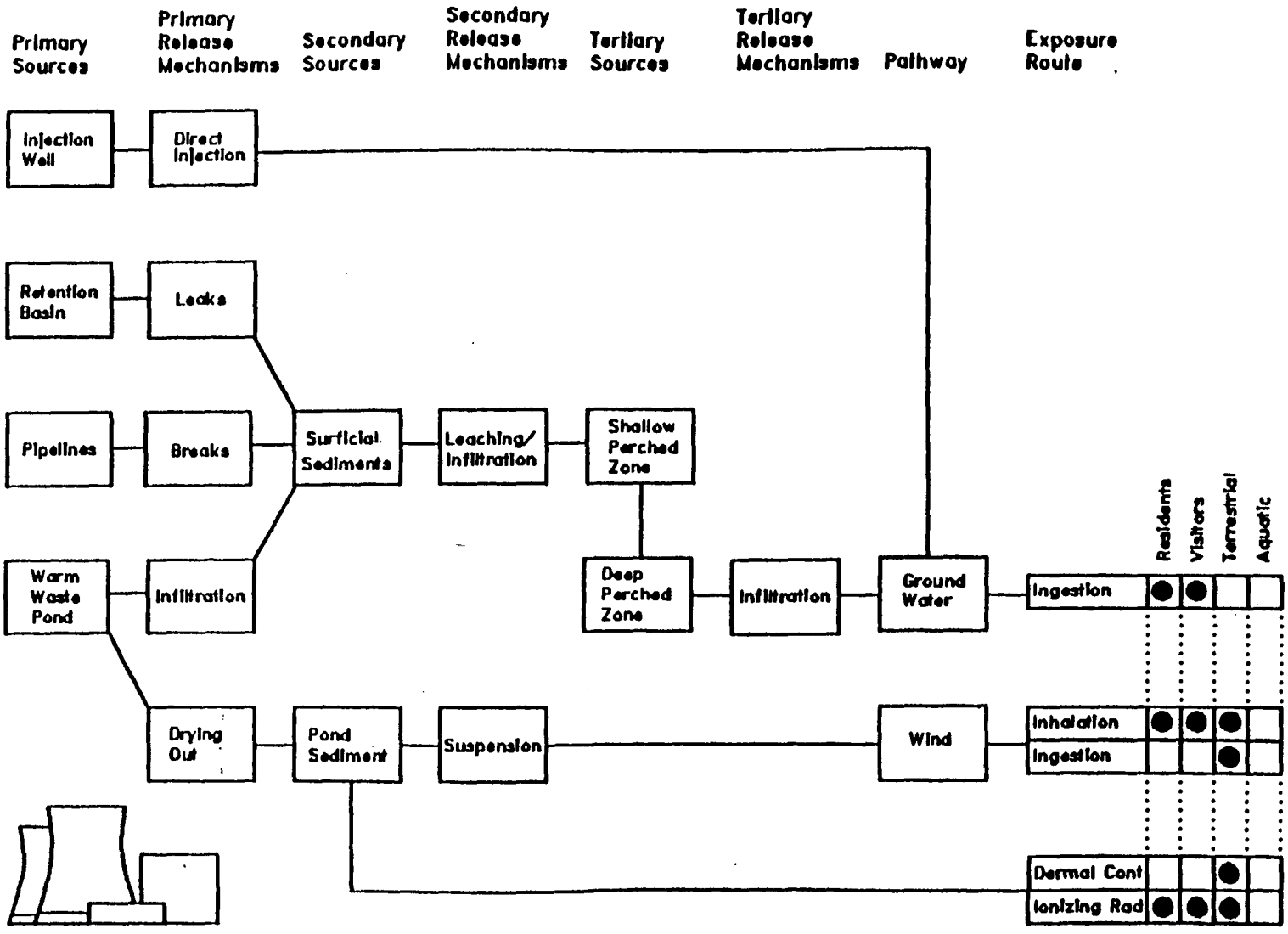


Figure 39. Conceptual model of TRA showing contaminant sources, release mechanisms, pathways, and exposure routes.

to water supply wells where INEL site employees could ingest the contaminants in drinking water.

A second mechanism for contaminant migration could occur if the Warm Waste Pond dries out. The water provides a radiation shield, and without the shield, employees and biota could receive a radiation exposure due to ionizing radiation. Windblown disposal of sediments from the pond could also result in exposure to employees and biota from inhalation or ingestion.

CONCLUSIONS

The hydrogeology of the vadose zone and Snake River Plain Aquifer at TRA are reasonably well understood. Details of the movement of water from the surface ponds to the aquifer need to be developed to better understand the occurrence of elevated levels of chromium in the shallow and deep perched water zones. The hydrogeology of well USGS-65 needs to be understood to determine if elevated concentrations of chromium in that well are being released to the aquifer. An understanding of the hydrogeology of well USGS-65 would also permit optimal remediation of the well if necessary.

A survey of water quality in the aquifer in the fall of 1987 showed elevated chromium concentrations in the aquifer in the vicinity of the RWMC. This chromium is at about the right distance downgradient from TRA to have originated in the Warm Waste Pond and Disposal Well. Since the extent of this contamination has not been determined, and the concentration of chromium in water from one well was at the drinking water standard, it is possible that concentrations above drinking water standards occur in the aquifer near the RWMC due to disposal at TRA.

Chromium still being released from the Warm Waste Pond at concentration levels that exceed the drinking water standard. Concentrations of chromium in the shallow perched water zone occasionally exceed the drinking water standard. The distribution of chromium, radionuclides, and other contaminants in the surficial sediments needs to be better evaluated to determine the potential for future migration. Even if the Warm Waste Pond is closed down, water from other sources, such as the Cold Waste Pond, Chemical Waste Pond, and possibly the leaky retention basin could be responsible for future migration of contaminants.

By study of the geochemical processes controlling the migration of chromium, and other contaminants, a better understanding of the conditions leading to immobilization of the contaminants will be obtained. This information will provide the data needed to evaluate remediation technologies and to evaluate any risks associated with leaving contaminants in place.

Estimates of the total amount of chromium in the sediments of the Warm Waste Pond and in the aquifer agree well with the estimated amount of chromium disposed of to the Warm Waste Pond and Disposal Well, respectively. Therefore, there is a general accounting for all the chromium discharged from TRA. While there is evidence that some of the chromium discharged to the Warm Waste Pond reached the aquifer, most of the chromium discharged to the pond remains in the pond sediments. Most of the aquifer contamination can be attributed to the Disposal Well.

Immediate risks to human health and the environment from chromium and radionuclide disposal at TRA appear to be very small. This is mainly due to the remote location of the site, the thick vadose zone, and the high flux through the Snake River Plain Aquifer. Well USGS-65, while appearing to represent a significant concern, probably taps a very small volume of contaminated water isolated from the rest of the aquifer. The major concerns are the continued release of chromium from pond sediments and the possible area of aquifer contamination near the RWMC.

REFERENCES

Anderson, J. E. and K. E. Holte, "Vegetation Development Over 25 Years Without Grazing on Sagebrush-Dominated Rangeland in Southeastern Idaho," Journal of Range Management, 34, 1981, pp. 25-29.

Armstrong, A. L., W. P. Leeman, and H. E. Malde, "Dating of Quaternary and Neocene Volcanic Rocks of the Snake River Plain, Idaho," American Journal of Science, 275, 1975, pp. 225-231.

Barraclough, J. T., B. D. Lewis, and R. G. Jensen, Hydrological Conditions at the Idaho National Engineering Laboratory, Idaho Emphasis: 1974-1978, Open-File Report 81-526, U. S. Geological Survey, Idaho Falls, Idaho, 1981.

Barraclough, J. T., W. E. Teasdale, and R. G. Jensen, Hydrology of the National Reactor Testing Station, Idaho: 1965, Open-File Report, U.S. Geological Survey, Idaho Falls, Idaho, 1967a.

Barraclough, J. T., W. E. Teasdale, J. B. Robertson, and R. G. Jensen, Hydrology of the National Reactor Testing Station, Idaho : 1966, IDO-22049, U.S. Geological Survey, Idaho Falls, Idaho, 1967b.

Bennett, C. M., Capacity of the Diversion Channel Below the Flood-Control Dam on the Big Lost River at the Idaho National Engineering Laboratory, Idaho, Water Resources Investigative Report 86-4204, U.S. Geological Survey, Idaho Falls, Idaho, 1986.

Bowman, A. L., W. F. Downs, K. S. Moor, and B. F. Russell, INEL Characterization Report, Vol. 2, EGG-NPR-6688, DOE Contract No. DE-AC07-761D01570, 1984.

Brown, J. C., Investigation of Stratigraphy and Groundwater Hydrology, Columbia River Basalt Group, Washington State University, College of Engineering Research Report 79/15-37, 1979.

Carrigan, P. H. Jr., Probability of Exceeding Capacity of Flood-Control System at the National Reactor Testing Station, Idaho, Open-File Report, Waste Disposal and Processing, TID-4500, IDO-22052, U.S. Geological Survey, Idaho Falls, Idaho, 1972.

Cholewa, A. F. and D. M. Henderson, A Survey and Assessment of the Rare Vascular Plants of the Idaho National Engineering Laboratory, DOE/ID-12100, 1984.

Eary, L. E. and D. Rai, "Chromate Removal from Aqueous Wastes by Reduction with Ferrous Ion," Environmental Science Technology, 2, 8, 1988, pp. 972-977.

Gleisner, D., "Idaho's Endangered Wildlife," Idaho Wildlife, 3, 2, 1983, pp. 11-22.

Hackett, W., J. Pelton, and C. Brockway, Geohydrologic Story of the Eastern Snake River Plain and the INEL, Idaho Falls, Idaho: U.S. Department of Energy-Idaho, 1986.

Halford, D. K., "Repopulation and Food Habits of Peromyscus maniculatus on a Burned Sagebrush Desert in Southeastern Idaho," Northwest Science, 55, 1981, pp. 44-49.

Hem, J. D., Study and Interpretation of the Chemical Characteristics of Natural Water, Water-Supply Paper 1473, U.S. Geological Survey, 1970.

Hoskinson, R. L. and J. R. Tester, "Migration Behavior of Pronghorn in Southeastern Idaho," Journal of Wildlife Management, 44, 1, 1980, pp. 132-144.

Hull, L. C. and T. R. Wood, Groundwater Monitoring Plan for the Test Reactor Area Paint Shop Ditch, Revision 1, EGG-ER-8523, Idaho National Engineering Laboratory, Idaho Falls, Idaho, 1989.

Jeppson, R. J. and K. E. Holte, (O. D. Markham ed.), "Flora of the Idaho National Engineering Laboratory Site," Ecological Studies of the Idaho National Engineering Laboratory Site, Progress Report, IDO-12087, 1978.

Jones, P. H. Hydrology of Waste Disposal, Open-File Report, IDO-22042, U.S. Geological Survey, 1961.

Koslow, K. N. and D. H. Van Haaften, Flood Routing Analysis for a Failure of Mackay Dam, EGG-EP-7184, 1986.

Kuntz, M. A. and G. B. Dalrymple, Geology, Geochronology, and Potential Hazards in the Lava Ridge-Hells Half Acre Area, Eastern Snake River Plain, Idaho, U.S. Geological Survey, Open-File Report 79-1657, 1979.

Lewis, B. D. and F. J. Goldstein, Evaluation of a Predictive Ground-Water Solute-Transport Model at the Idaho National Engineering Laboratory, USGS Water-Resources Investigations 82-25, 1982.

Linsley, R. K., M. A. Kohler, and J. L. H. Paulhus, Hydrology for Engineers, New York: McGraw-Hill Book Co., 1982.

Litteer, D. L., Industrial Waste Management Information for 1987 and Record-to-Date, DOE/ID-10057(87), U.S. Department of Energy, Idaho Falls, Idaho, 1988.

Mann, L. J., Hydraulic Properties of Rock Units and Chemical Quality of Water for INEL-1, A 10,365-foot Deep Test Hole Drilled at the Idaho National Engineering Laboratory, IDO-22070, U.S. Geological Survey, Open-File Report 86-4020, 1986.

Mann, L. J. and L. L. Knobel, Concentrations of Nine Trace Metals in Ground Water at the Idaho National Engineering Laboratory, DOE/ID-22075, U.S. Geological Survey, 1988.

McBratney, A. B. and R. Webster, "How Many Observations are Needed for Regional Estimation of Soil Properties?," Soil Science, 135, 3, 1983, pp. 177-183.

McBride, R., N. R. French, A. H. Dahl, and J. E. Detmer, Vegetation Types and Surface Soils of the Idaho National Engineering Laboratory Site, IDO-12-84, U.S. Department of Energy, Idaho Operations Office, Idaho Falls, Idaho, 1978.

Morris, D. A., G. M. Hogenson, W. E. Teasdale, and E. Shuter, Hydrology of Waste Disposal, National Reactor Testing Station, Idaho, IDO-22044, U.S. Geological Survey, Annual Progress Report, 1963, p. 99.

Morris, D. A., W. E. Teasdale, G. H. Chase, G. M. Hogenson, J. T. Barraclough, and E. Shuter, Hydrology of Subsurface Waste Disposal, National Reactor Testing Station, Idaho, IDO-22046, U.S. Geological Survey, Annual Progress Report, 1964.

Morris, D. A., J. T. Barraclough, G. H. Chase, W. E. Teasdale, and R. G. Jensen, Hydrology of Subsurface Waste Disposal, National Reactor Testing Station, Idaho, IDO-22047, U.S. Geological Survey, Annual Progress Report, 1965.

Mundorff, M. J., E. G. Crosthwaite, and Chabot Kilburn, Ground Water for Irrigation in the Snake River Basin in Idaho, U.S. Geological Survey, Water Supply Paper 1654, 1964.

Nace, R. L., M. Deutsch, and P. T. Voegeli, Geography, Geology, and Water Resources of the National Reactor Testing Station, Idaho, IDO-22033, U.S. Geological Survey, 1956.

Pittman, J. R., R. G. Jensen, and P. R. Fischer, Hydrologic Conditions at the Idaho National Engineering Laboratory, 1982 to 1985, U.S. Geological Survey, Water-Resources Investigation Report 89-4008, 1988, p. 73.

Pourbaix, M., Atlas of Electrochemical Equilibria in Aqueous Solutions, Houston: National Association of Corrosion Engineers, 1974.

Prestwich, S. M. et al., Completion and Testing Report: INEL Geothermal Exploratory Well One (INEL-1), U.S. Department of Energy, Idaho Operations Office, 1980.

Rehak, E. M., Statistical Analysis of TRA Warm Waste Pond Chemical Data, EG&G Idaho, Inc., EGG-SARE-8712, 1989.

Reynolds, T. D. and F. L. Rose, (O. D. Markham ed.), "Pronghorn Antelope Use of the INEL National Environmental Research Park," Ecological Studies on the Idaho National Engineering Laboratory Site 1978 Progress Report, IDO-12087, 1978. pp. 219-223.

Robertson, J. B., Digital Modeling of Radioactive and Chemical Waste Transport in the Snake River Plain Aquifer at the National Reactor Testing Station, Idaho, IDO-22054, U.S. Geological Survey, 1974.

Robertson, J. B., Numerical Modeling of Subsurface Radioactive Solute Transport from Waste-Seepage Ponds at the Idaho National Engineering Laboratory, IDO-22057, U.S. Geological Survey, Open-File Report 76-717, 1977.

Robertson, J. B., R. Schoen, and J. T. Barraclough, The Influence of Liquid Waste Disposal on the Geochemistry of Water at the NRTS, Idaho: 1952-1970, IDO-22053, U.S. Geological Survey, 1974.

Schmalz, B. L., Radionuclide Distribution in Soil Mantle of the Lithosphere as a Consequence of Waste Disposal at the National Reactor Testing Station, IDO-10049, U.S. Atomic Energy Agency, 1972.

Schroeder, D. C. and G. F. Lee, "Potential Transformations of Chromium in Natural Waters," Water, Air, and Soil Pollution, 4, 1975, pp. 355-365

Sehman, R. W., and A. D. Linder, Amphibian and Reptilian Fauna of the Idaho National Engineering Laboratory Site, IDO-12086, U.S. Department of Energy, Idaho Falls, Idaho, 1978.

Thomas, T. R., N. A. Chipman, and J. R. Berreth, Impact of Rain, Flood, and River Water on Potential Near-Surface Disposal of High-Level Radioactive Waste at the Idaho Chemical Processing Plant, WINCO-1042, Westinghouse Idaho Nuclear Company, Idaho Falls, Idaho, 1986.

U.S. Environmental Protection Agency, Test Methods for Evaluating Solid Waste, SW-846, 1986a.

VanDeusen, L. C. and L. C. Hull, TRA Warm Waste Pond Corrective Action Workplan, EG&G Idaho, Inc., 1988.

Walker, E. H., Analysis of Aquifer Tests, January 1958 - June 1959, at the NRTS, Idaho, IDO-22040-USGS, U.S. Geological Survey, 1960.

W. C. Walton, Analysis of Aquifer Tests at the National Reactor Testing Station, Idaho: 1949-1957, IDO-22034, U.S. Geological Survey, 1958.

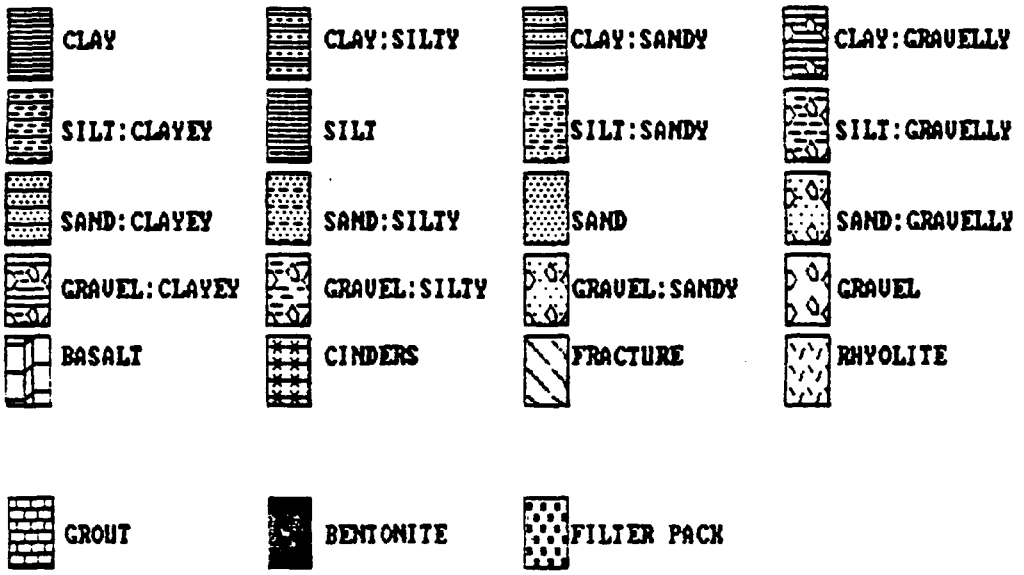
Wood, T. R., L. C. Hull, and M. H. Doornbos, Groundwater Monitoring Plan and Interim Status Report for Central Facilities Landfill II, EGG-ER-8496, Idaho National Engineering Laboratory, 1989.

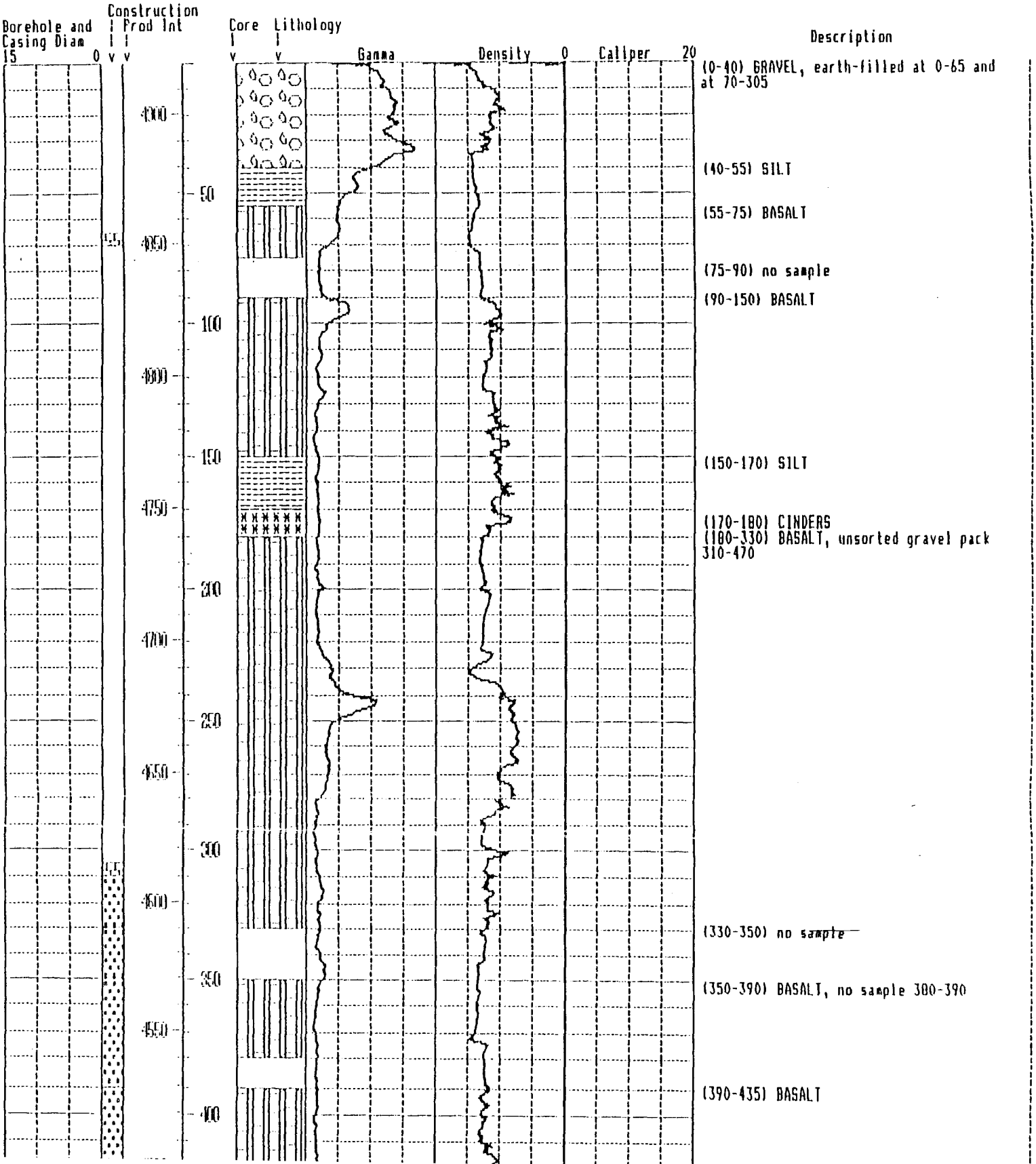
Zachara, J. M., C. C. Ainsworth, C. E. Cowan, and C. T. Resch, "Adsorption of Chromate by Subsurface Soil Horizons," Soil Science Society of America Journal, 53, 1989, pp. 418-428.

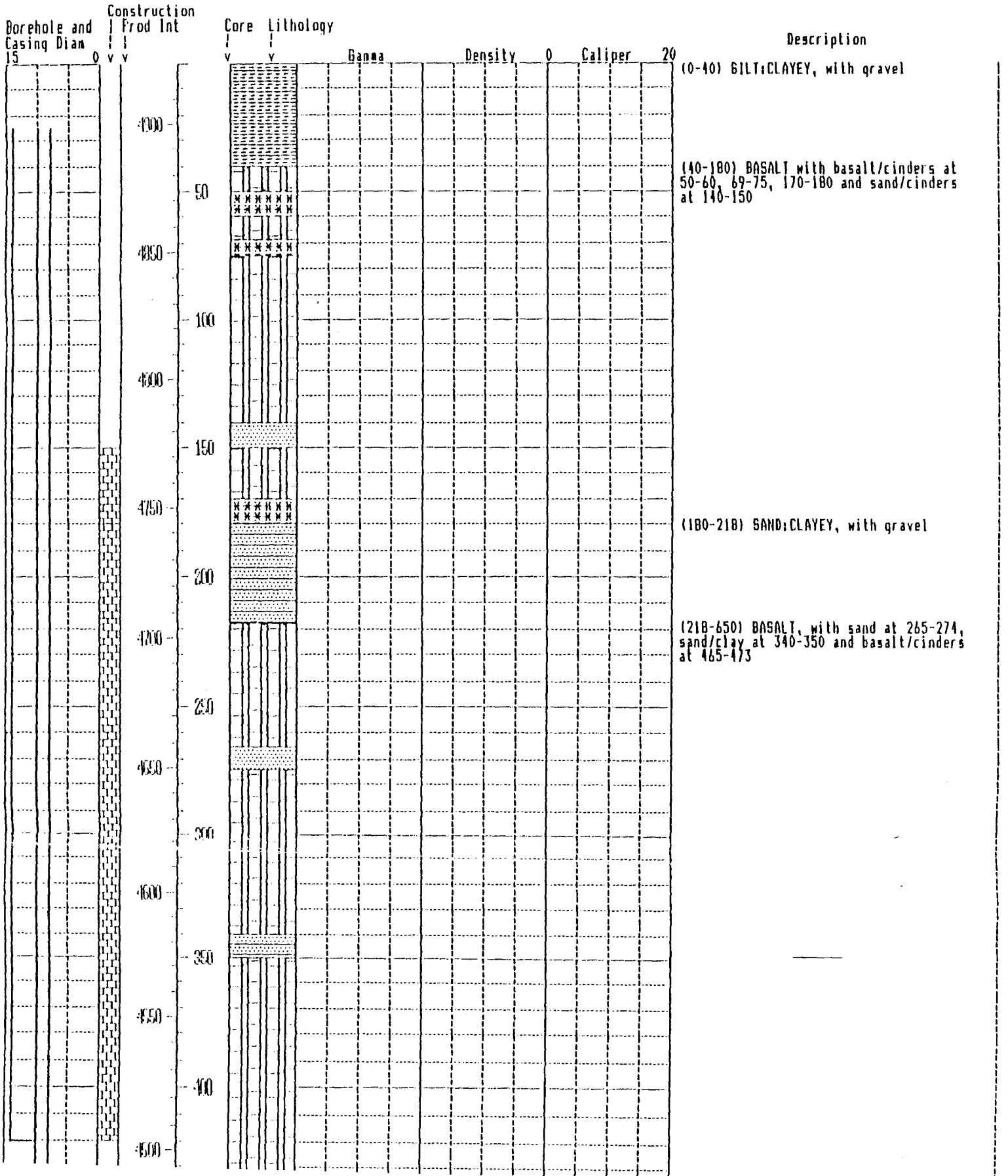
APPENDIX A

SELECTED LITHOLOGIC AND GEOPHYSICAL LOGS FROM WELLS AT TRA

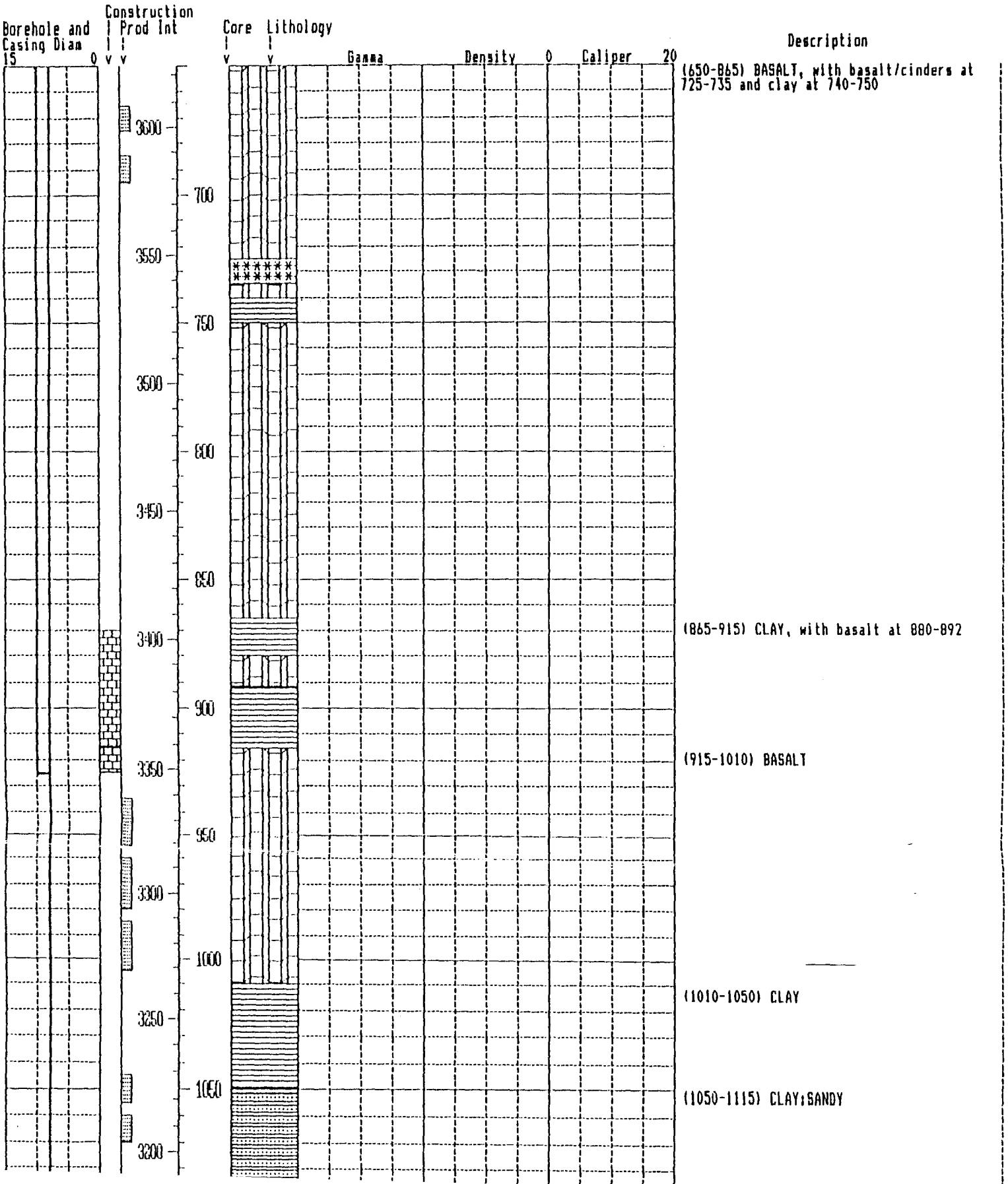
INDEX TO SYMBOLS

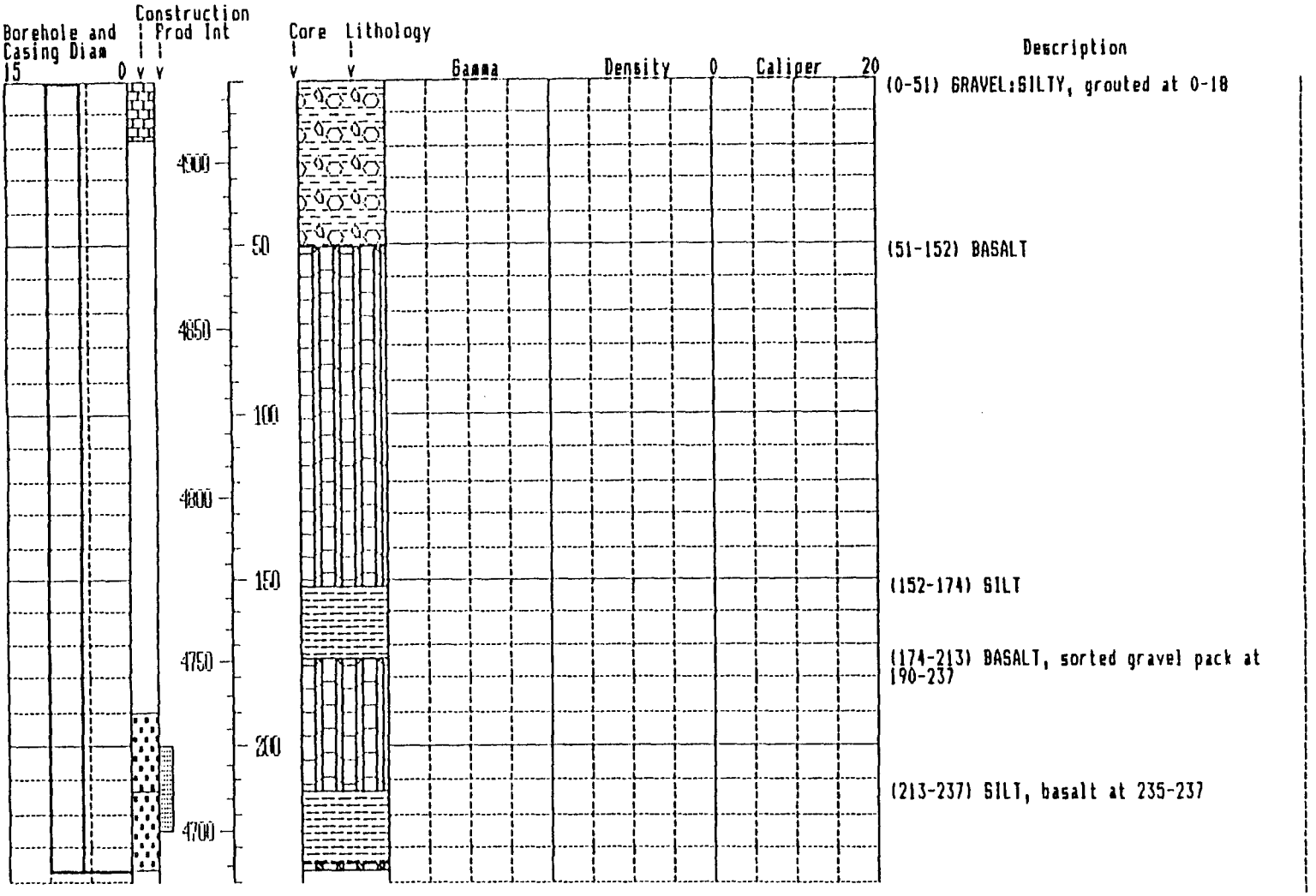


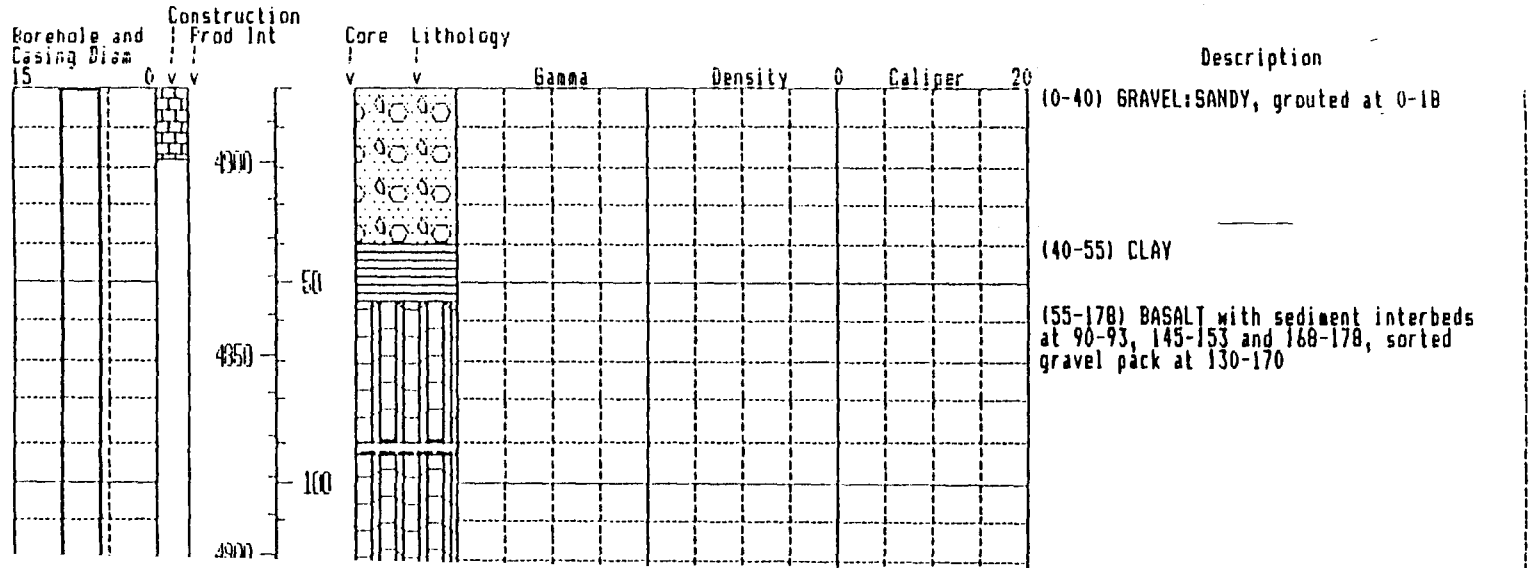

Borehole and Casing Diam
15
0
Construction
Prod Int
Core
Lithology
Gamma
Density
0
Caliper
20
Description
(0-40) GRAVEL, earth-filled at 0-65 and at 70-305
(40-55) SILT
(55-75) BASALT
(75-90) no sample
(90-150) BASALT
(150-170) SILT
(170-180) CINDERS
(180-330) BASALT, unsorted gravel pack 310-470
(330-350) no sample
(350-390) BASALT, no sample 380-390
(390-435) BASALT


Borehole and Casing Diam
15
0
Construction
Prod Int
Core
Lithology
Gamma
Density
0
Caliper
20
Description
(0-40) SILT:CLAYEY, with gravel
(40-180) BASALT with basalt/cinders at 50-60, 69-75, 170-180 and sand/cinders at 140-150
(180-218) SAND:CLAYEY, with gravel
(218-650) BASALT, with sand at 265-274, sand/clay at 340-350 and basalt/cinders at 465-473
4900
4850
4800
4750
4700
4650
4600
4550
4500
50
100
150
200
250
300
350
400

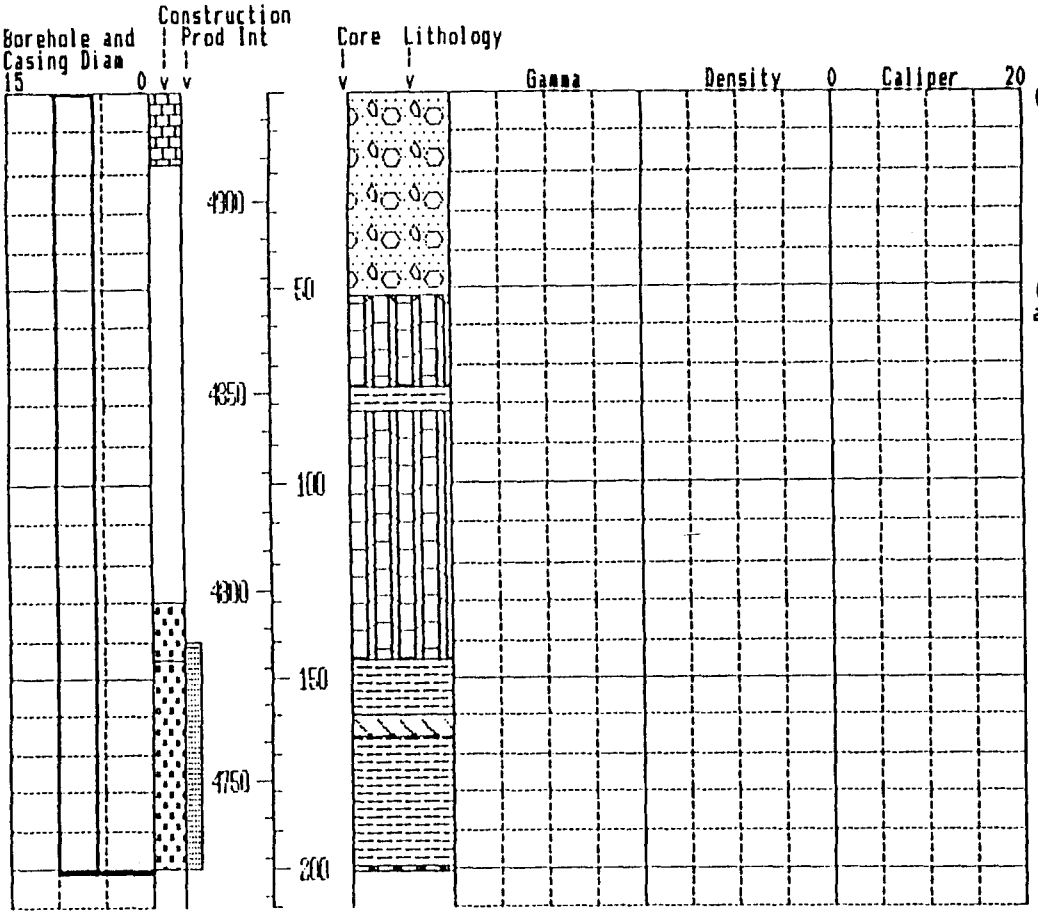
WELL: TRA DISPOSAL (continued)




Borehole and Casing Diam
15
0
Construction
Prod Int
Core
Lithology
Gamma
Density
0
Caliper
20
4900
4850
4800
4750
4700
50
100
150
200
Description
(0-51) GRAVEL:SILTY, grouted at 0-18
(51-152) BASALT
(152-174) SILT
(174-213) BASALT, sorted gravel pack at 190-237
(213-237) SILT, basalt at 235-237


Borehole and Casing Diam
15
0
Construction
Prod Int
Core
Lithology
Gamma
Density
0
Caliper
20
4900
4850
4900
50
100
Description
(0-40) GRAVEL:SANDY, grouted at 0-18
(40-55) CLAY
(55-178) BASALT with sediment interbeds at 90-93, 145-153 and 168-178, sorted gravel pack at 130-170

WELL: PW-07



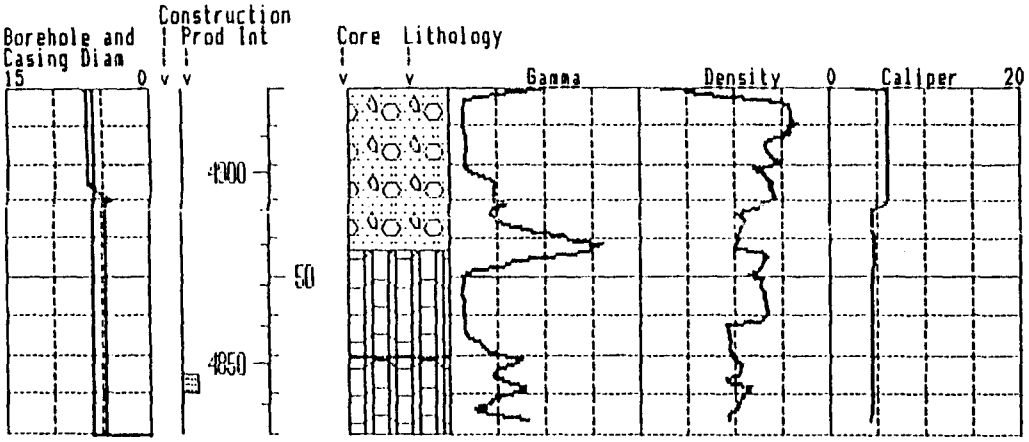
Description

(0-52) GRAVEL;SANDY grouted at 0-18

(52-145) BASALT with sediment interbed at 76-82, sorted gravel pack at 130-200

(145-201) SILT with fractured basalt at 160-165 and basalt at 199-201

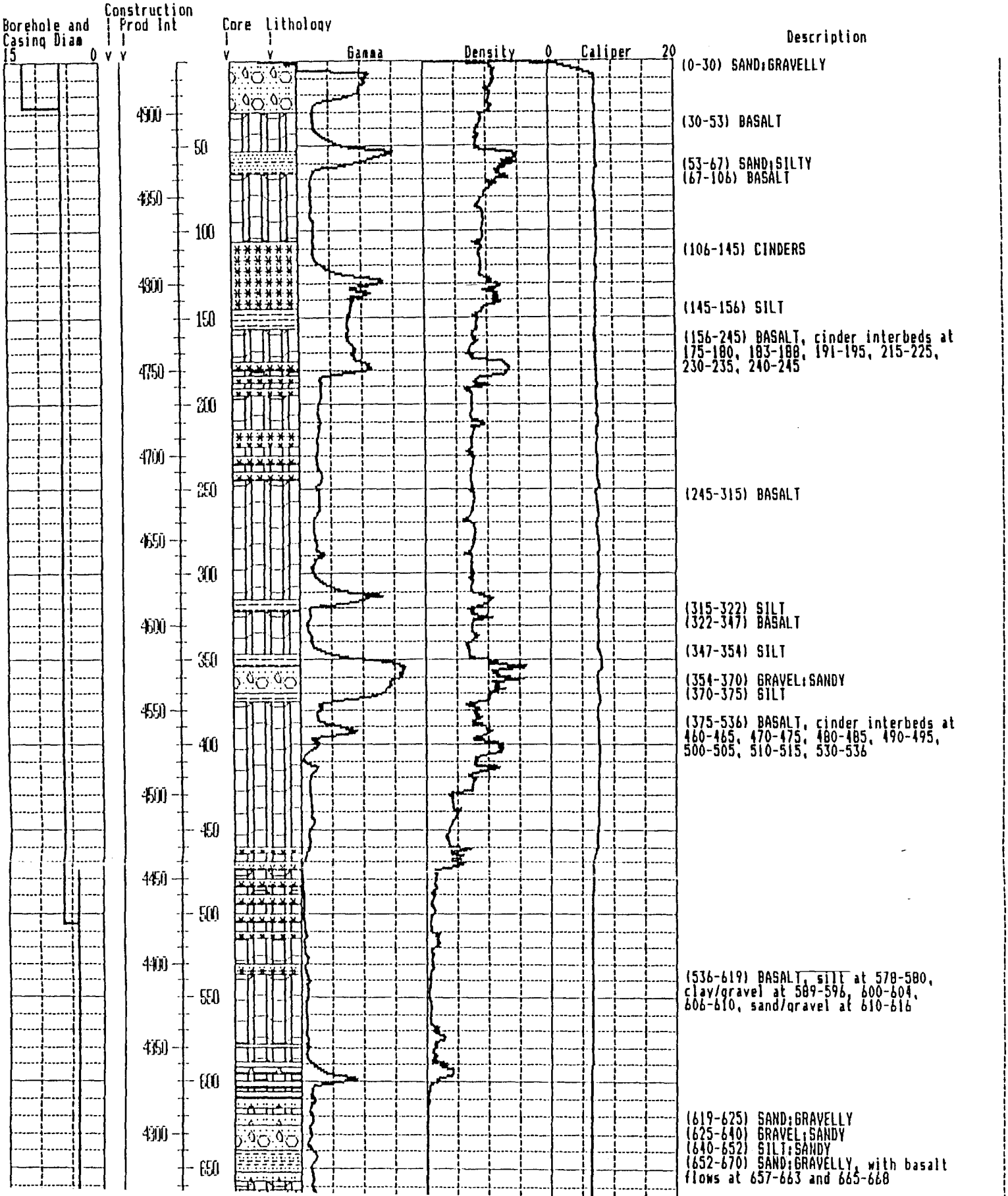
WELL: USGS-07



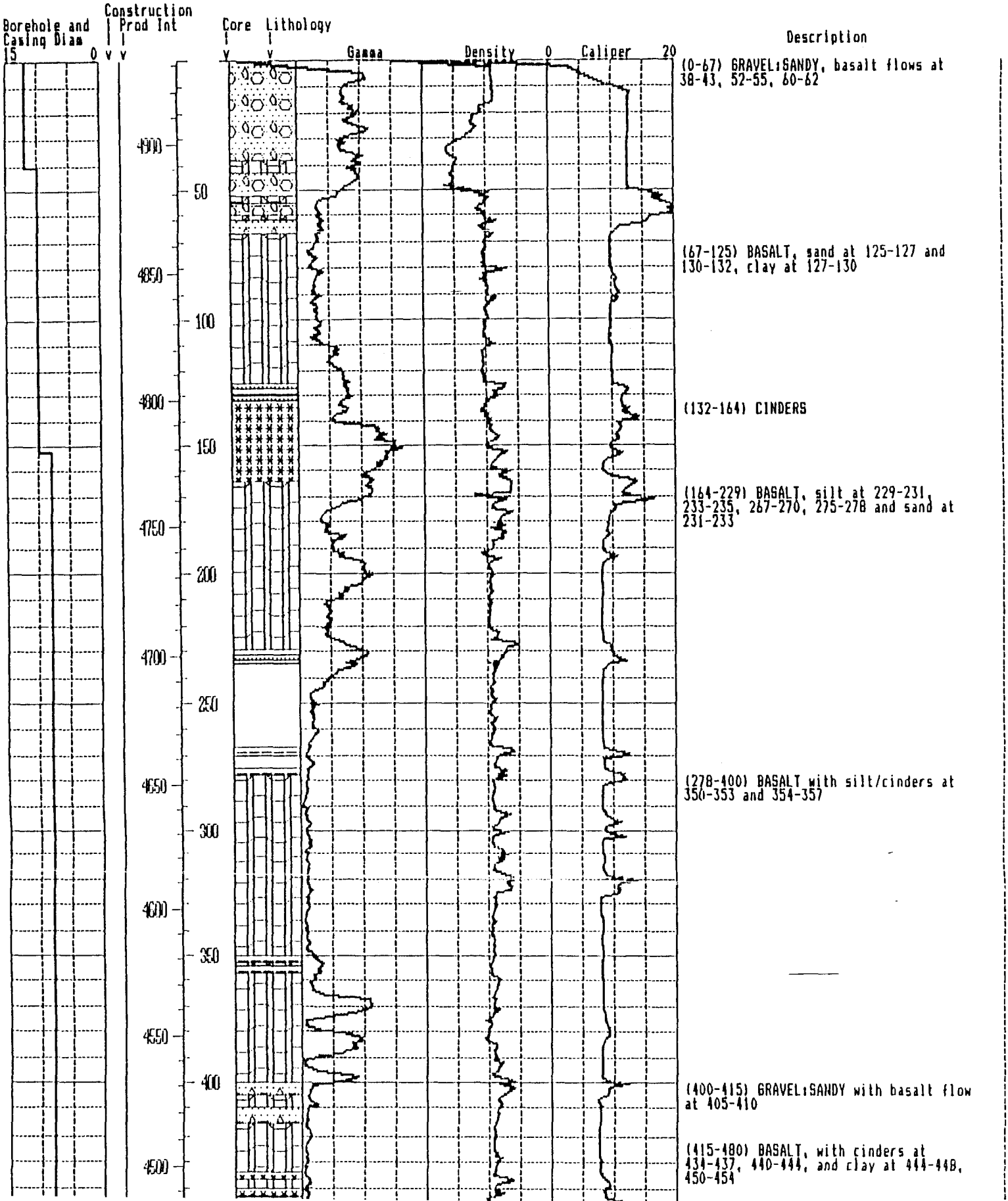
Description

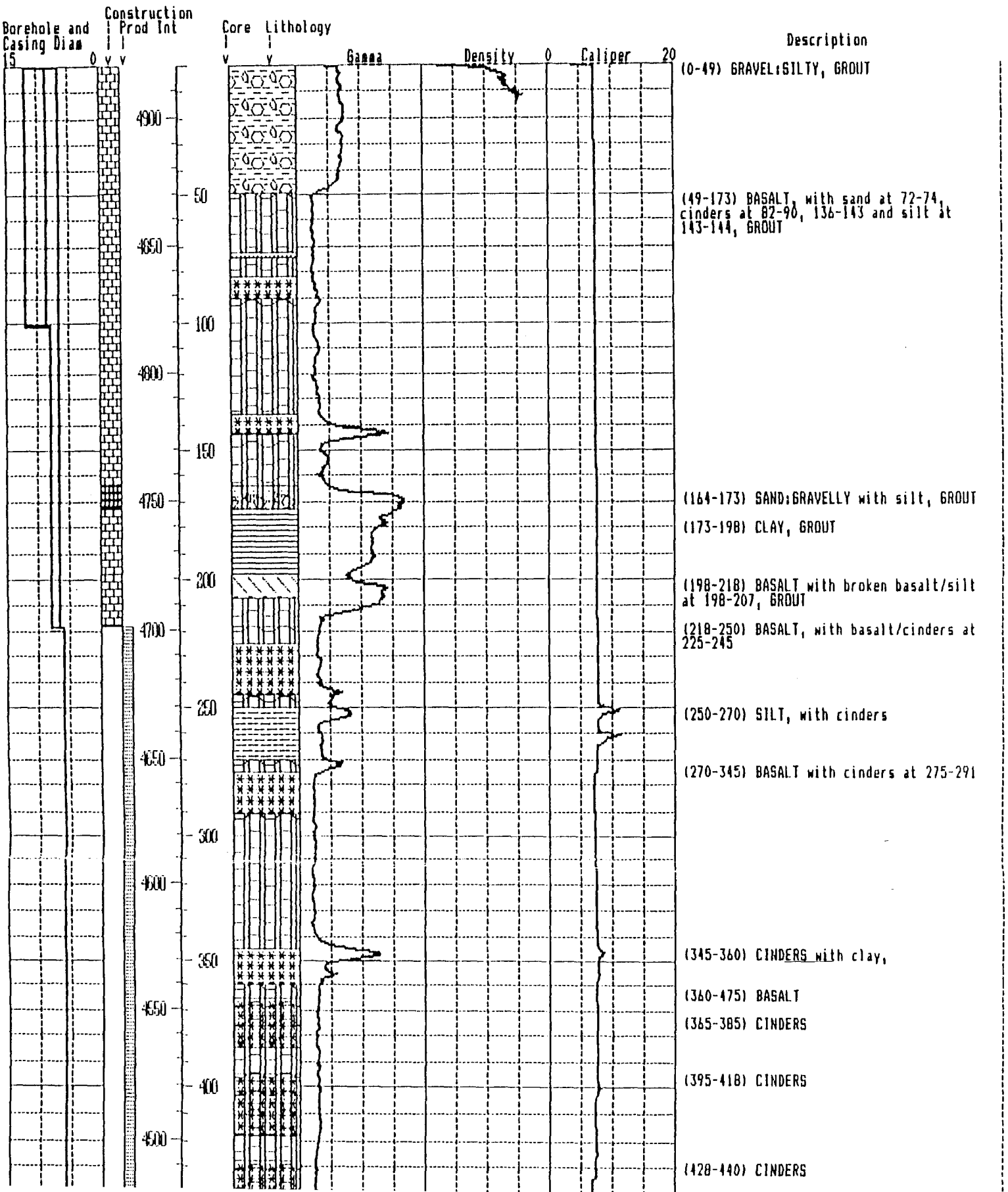
(0-44) SAND;GRAVELLY, with clay

(44-90) BASALT with cinders at 70-71

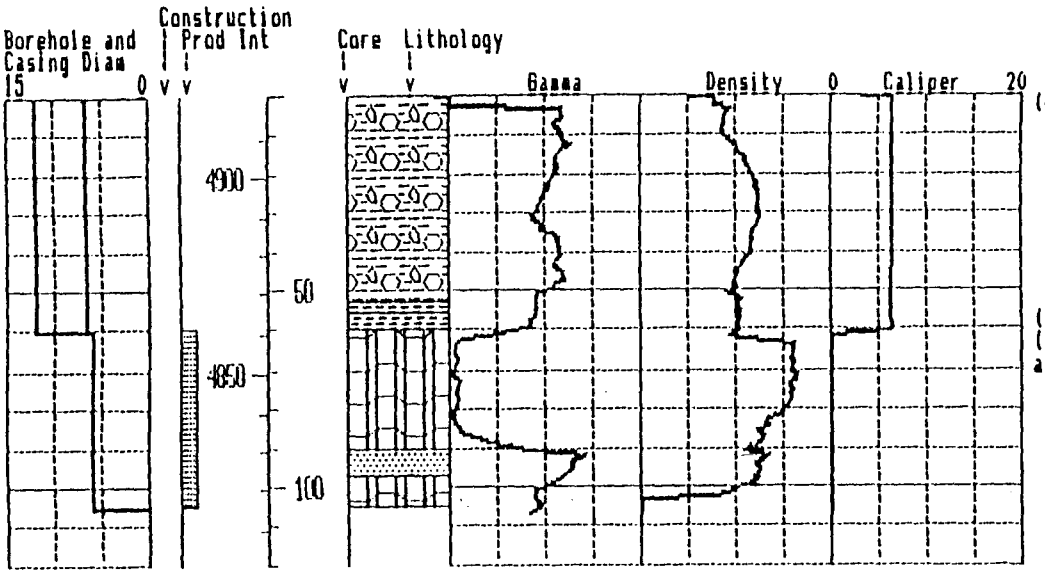

Borehole and Casing Diam
15
0
Construction
Prod Int
Core Lithology
Gamma
Density
0
Caliper
20
Description
4900
50
4850
100
4800
150
4750
200
4700
250
4650
300
4600
350
4550
400
4500
450
4450
500
4400
550
4350
600
4300
650
(0-30) SAND;GRAVELLY
(30-53) BASALT
(53-67) SAND;SILTY
(67-106) BASALT
(106-145) CINDERS
(145-156) SILT
(156-245) BASALT, cinder interbeds at 175-180, 183-188, 191-195, 215-225, 230-235, 240-245
(245-315) BASALT
(315-322) SILT
(322-347) BASALT
(347-354) SILT
(354-370) GRAVEL;SANDY
(370-375) SILT
(375-536) BASALT, cinder interbeds at 460-465, 470-475, 480-485, 490-495, 500-505, 510-515, 530-536
(536-619) BASALT, silt at 578-580, clay/gravel at 589-596, 600-604, 606-610, sand/gravel at 610-616
(619-625) SAND;GRAVELLY
(625-640) GRAVEL;SANDY
(640-652) SILT;SANDY
(652-670) SAND;GRAVELLY, with basalt flows at 657-663 and 665-668

WELL: USGS-039




Borehole and Casing Diam
15
0
Construction
Prod Int
Core
Lithology
Gamma
Density
0
Caliper
20
Description
4900
4850
4800
4750
4700
4650
4600
4550
4500
50
100
150
200
250
300
350
400
(0-49) GRAVEL:SILTY, GROUT
(49-173) BASALT, with sand at 72-74, cinders at 82-90, 136-143 and silt at 143-144, GROUT
(164-173) SAND:GRAVELLY with silt, GROUT
(173-198) CLAY, GROUT
(198-218) BASALT with broken basalt/silt at 198-207, GROUT
(218-250) BASALT, with basalt/cinders at 225-245
(250-270) SILT, with cinders
(270-345) BASALT with cinders at 275-291
(345-360) CINDERS with clay,
(360-475) BASALT
(365-385) CINDERS
(395-418) CINDERS
(428-440) CINDERS

WELL: USGS-060

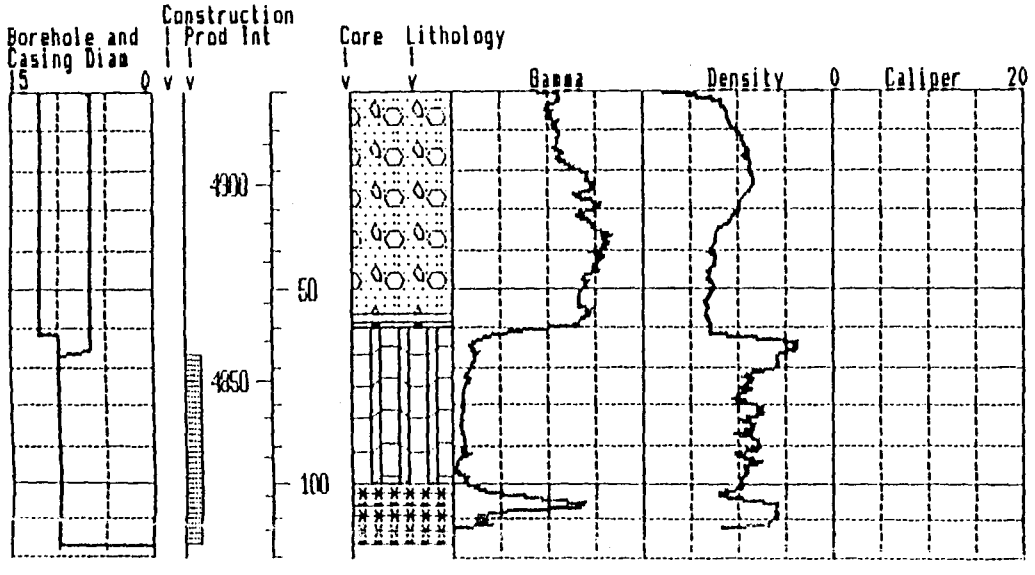


Description

(0-53) SILT:GRAVELLY

(53-60) SILT:CLAYEY
(60-105) BASALT with broken basalt/sand at 90-97

WELL: USGS-061



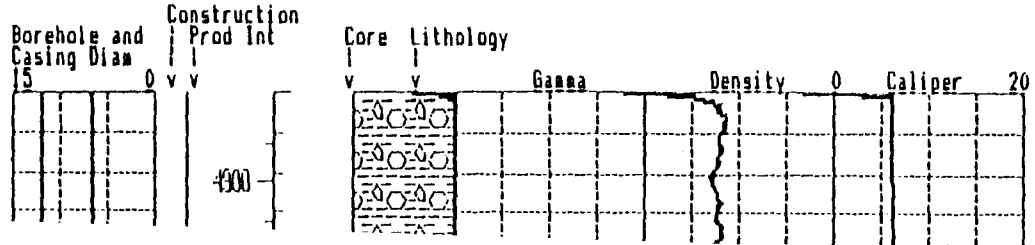
Description

(0-56) SAND:GRAVELLY

(56-100) BASALT clay/gravel at 56-60 and cinders/broken basalt at 100-106

(106-117) CINDERS with silt

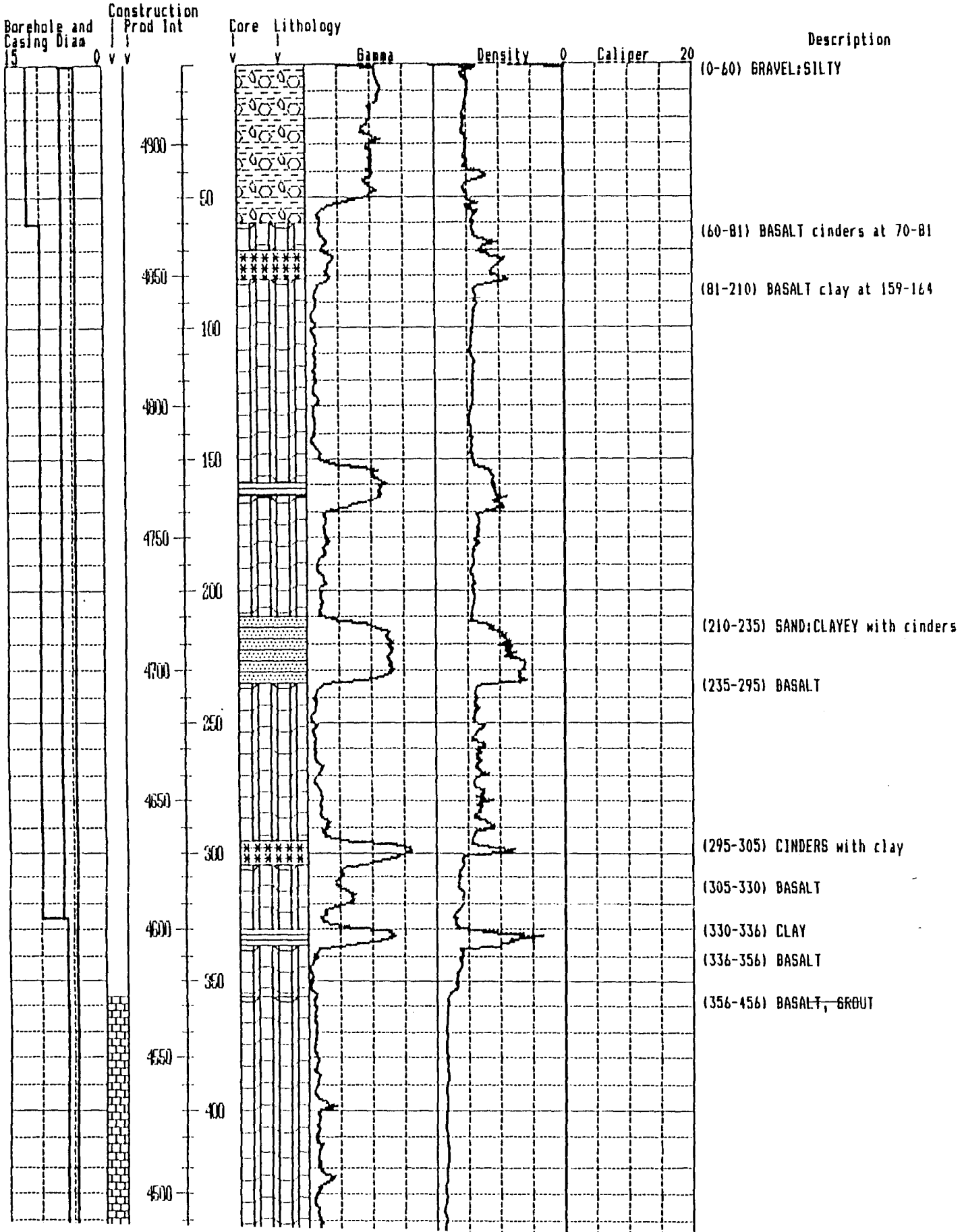
WELL: USGS-062



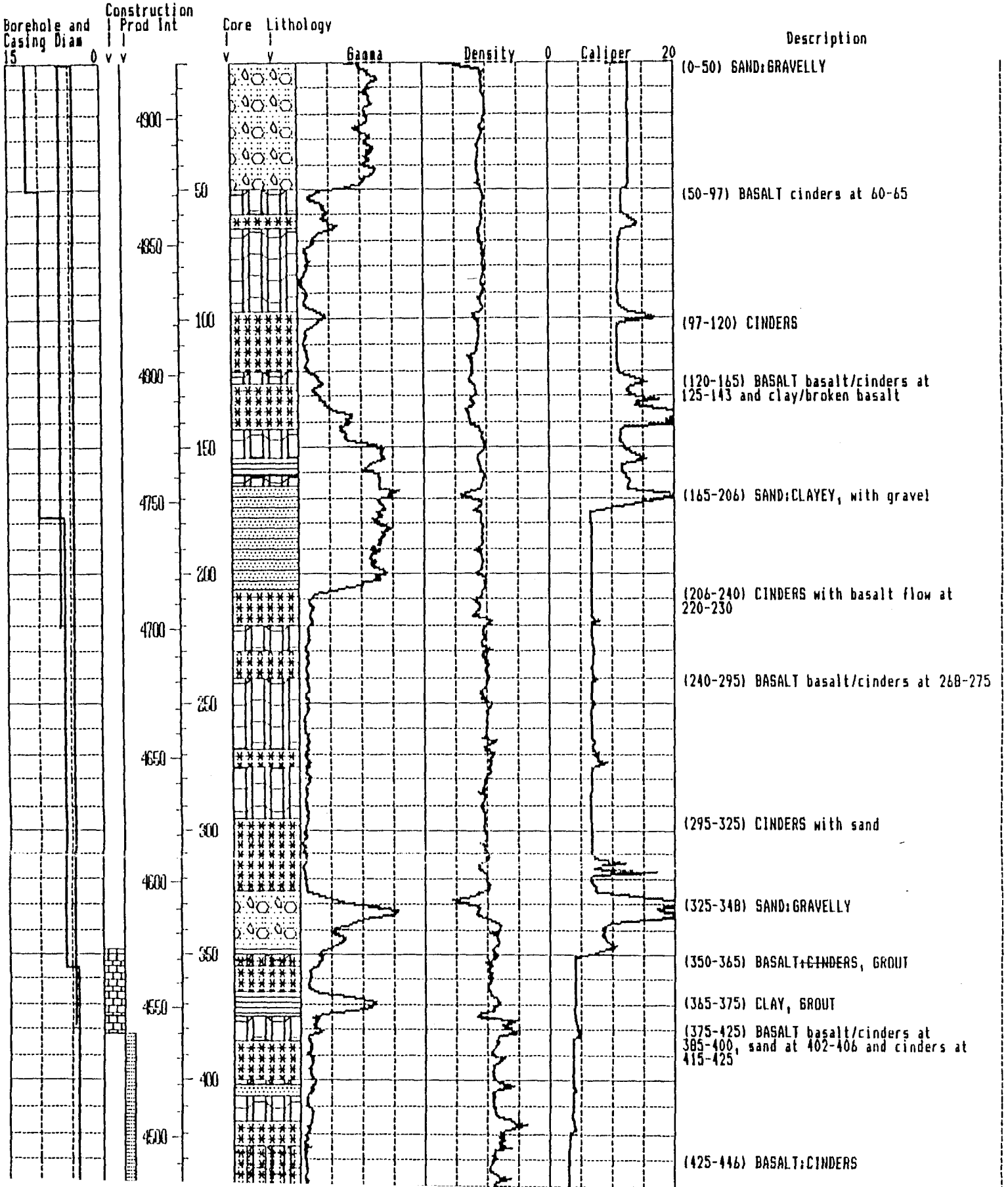
Description

(0-55) SILT:GRAVELLY

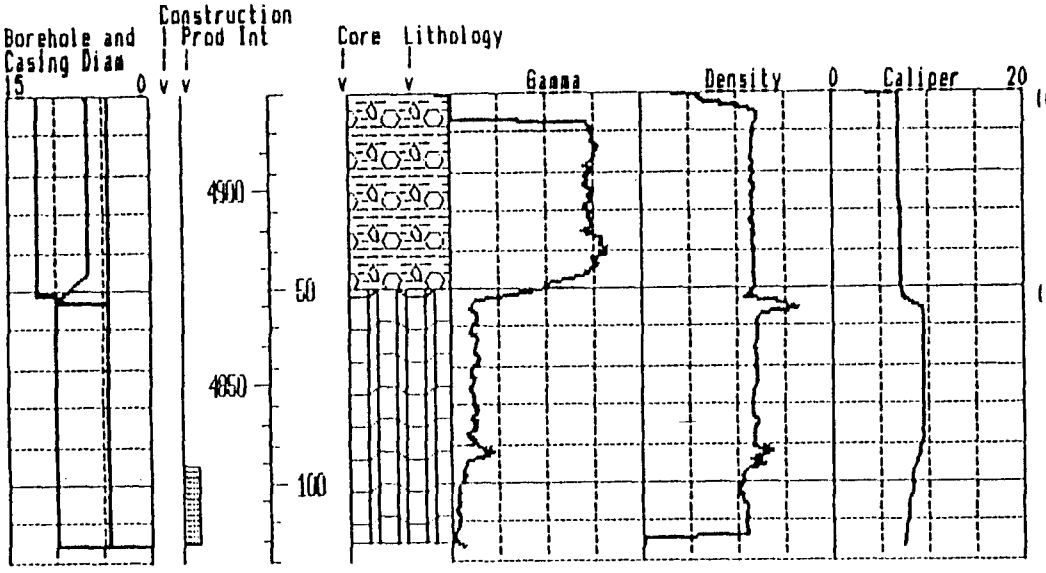
WELL: USGS-065



WELL: USGS-066



WELL: USGS-059

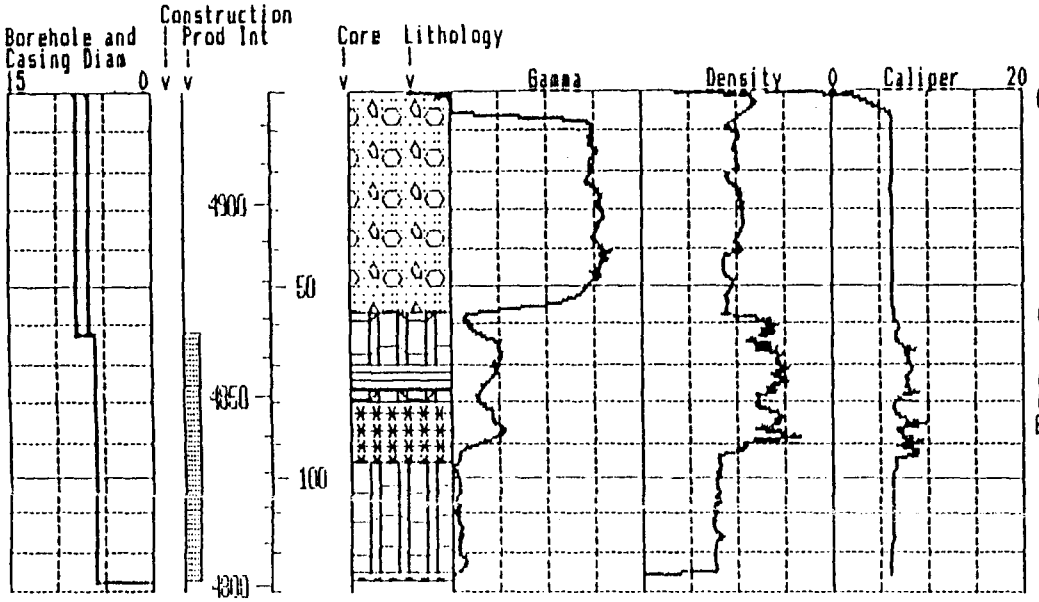


Description

(0-50) SILT:GRAVELLY

(50-115) BASALT

WELL: USGS-073



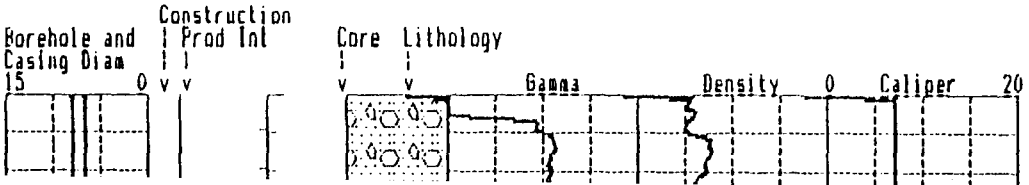
Description

(0-57) SAND:GRAVELLY with clay

(57-70) BASALT

(70-77) CLAY with cinders
(77-127) BASALT basalt/cinder/clay at 80-96 and cinders at 125-127

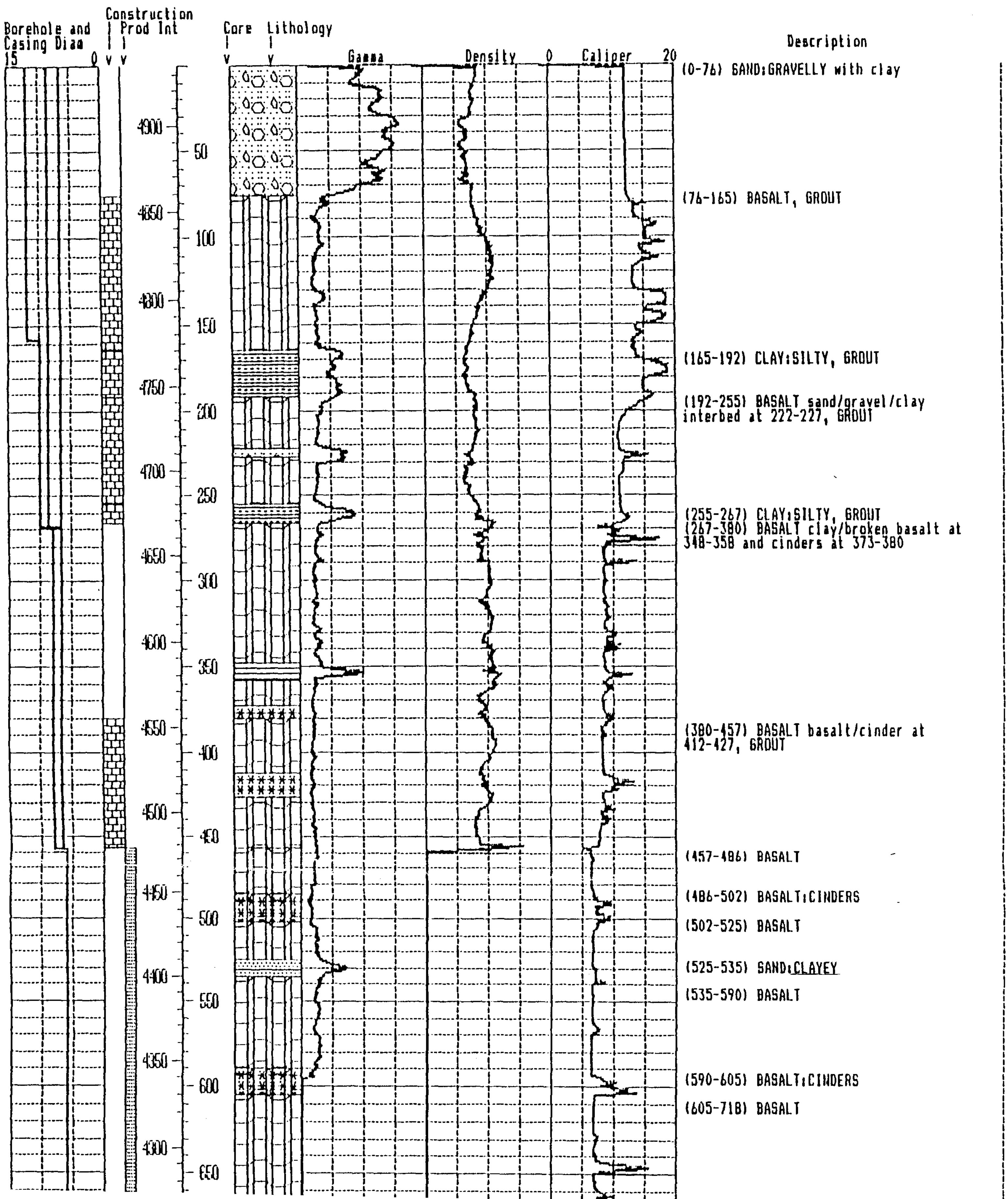
[illegible]



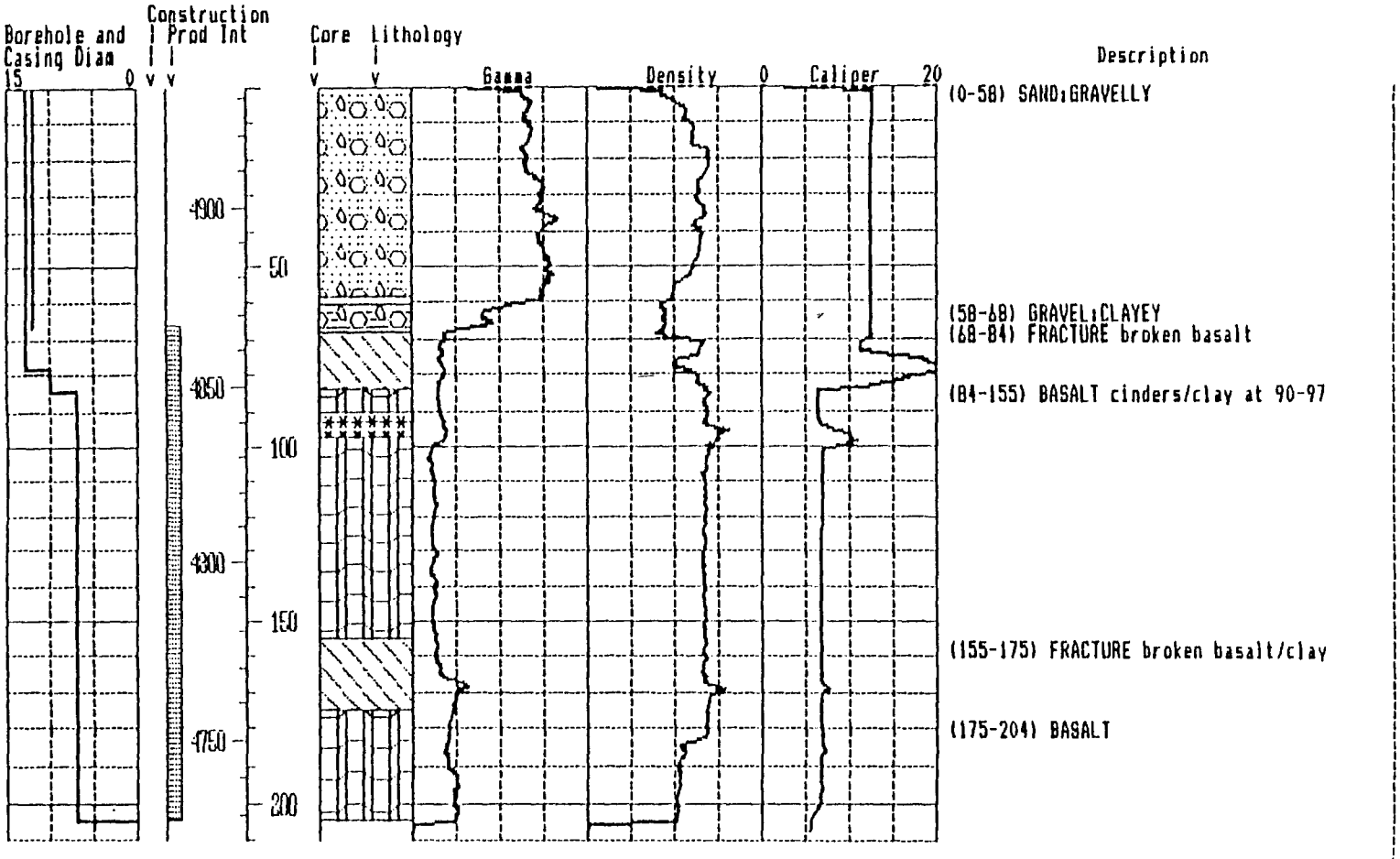
Description

(0-31) SAND:GRAVELLY

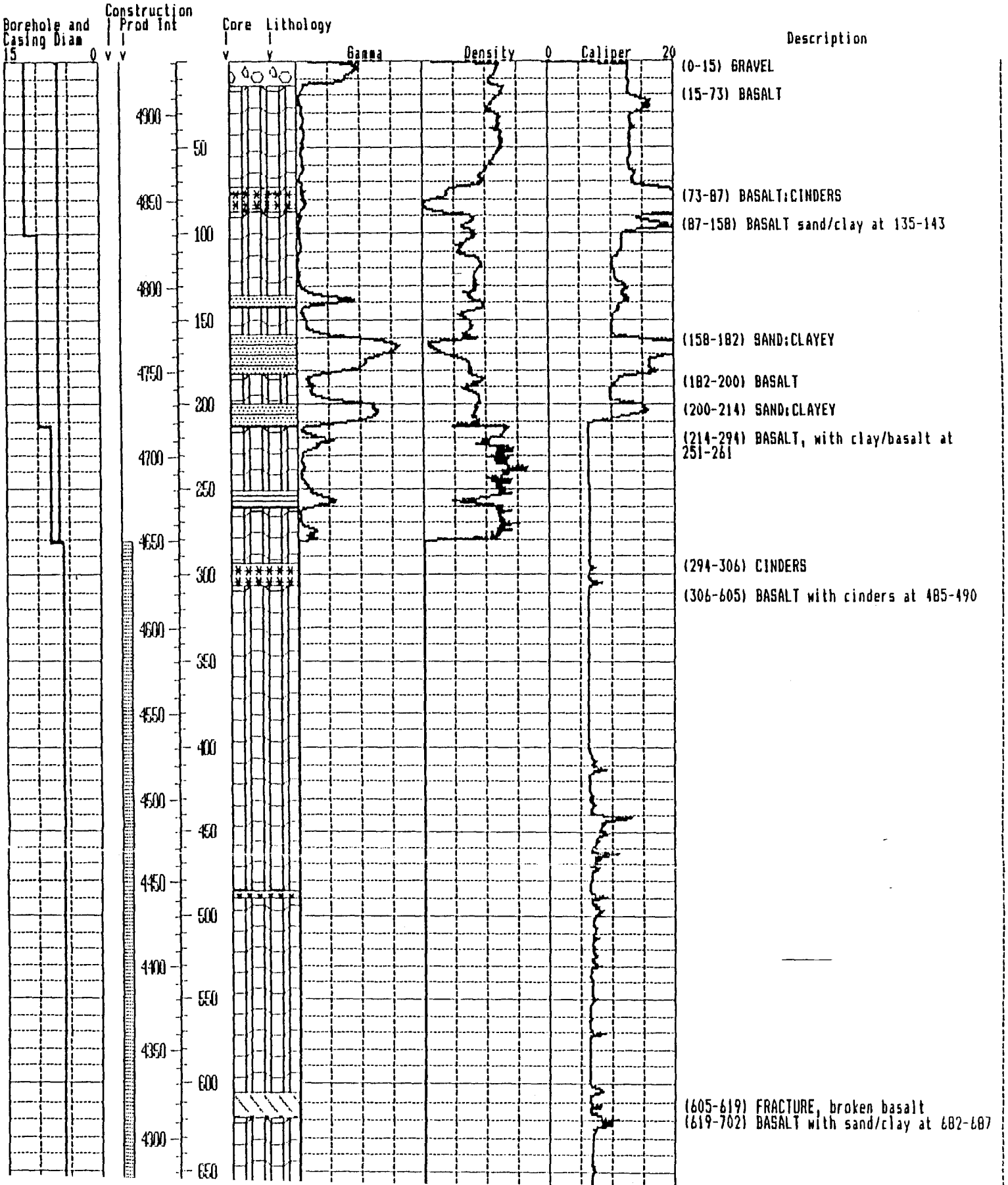
WELL: USGS-076



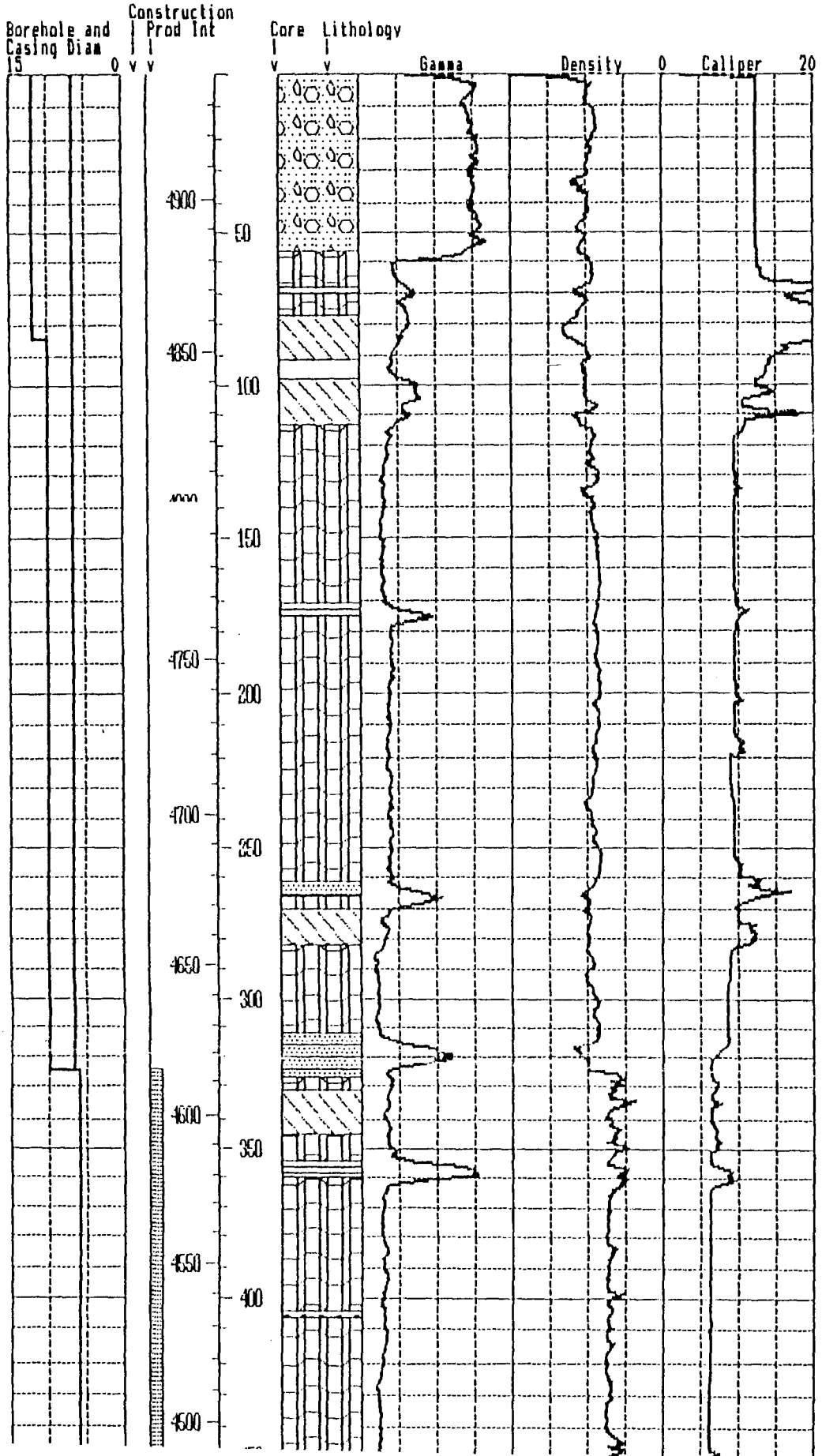
WELL: U565-07B



WELL : USGS-079



WELL: USGS-OB4



Description

(0-56) SAND;GRAVELLY

(56-77) BASALT with clay/cinders at 68-70

(77-92) FRACTURE broken basalt

(98-113) FRACTURE, filled with clay

(113-270) BASALT clay/cinders at 171-175 and sand/clay at 261-266

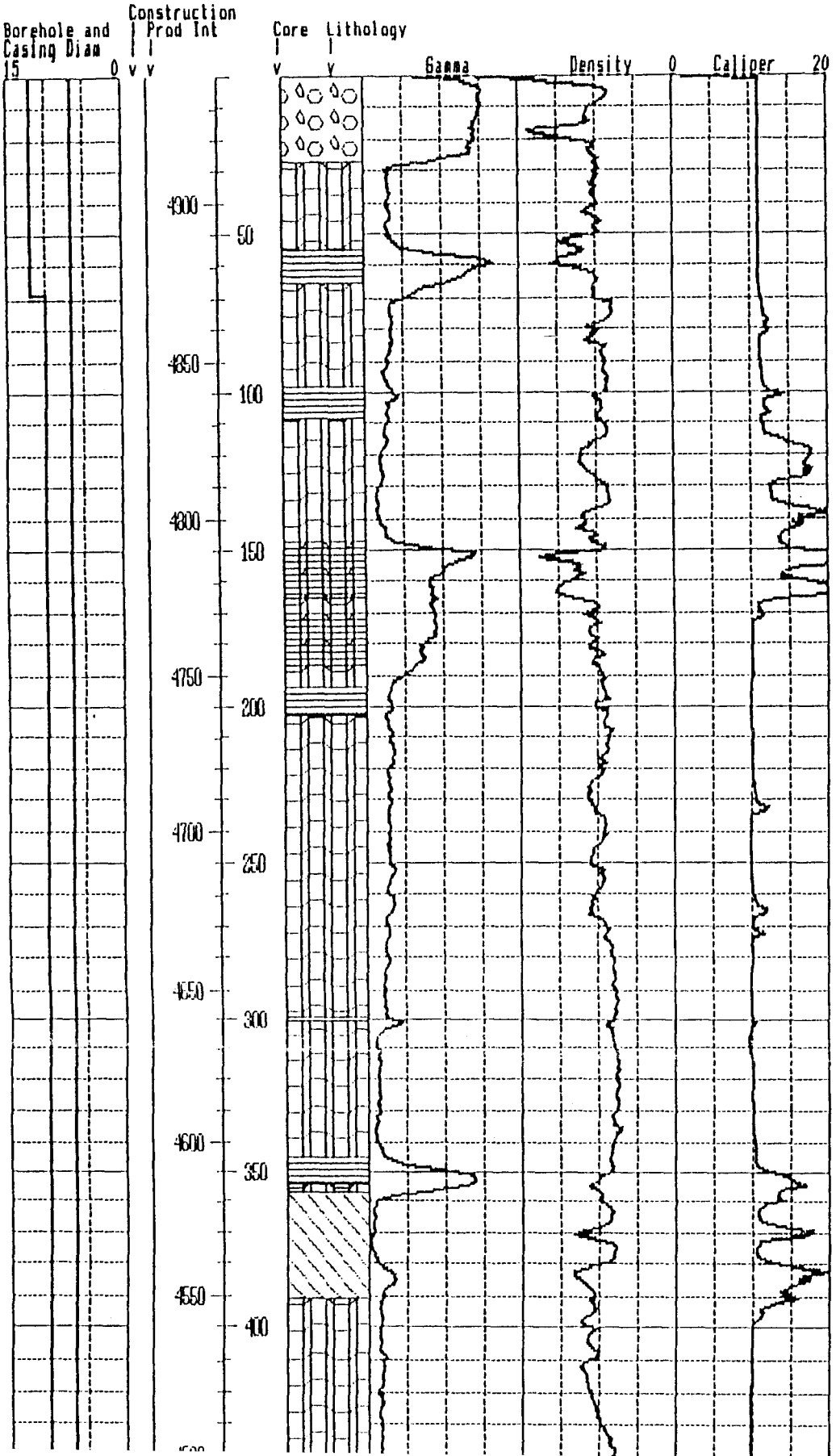
(270-282) FRACTURE, filled with clay

(282-312) BASALT

(312-327) SAND;CLAYEY, broken basalt

(327-490) BASALT, broken basalt at 331-345, 404-406 and clay at 354-360

WELL : USGS-085



Description

(0-27) GRAVEL

(27-55) BASALT with clay at 55-65

(65-147) BASALT with clay/basalt at 98-108

(147-170) CLAY:BASALT

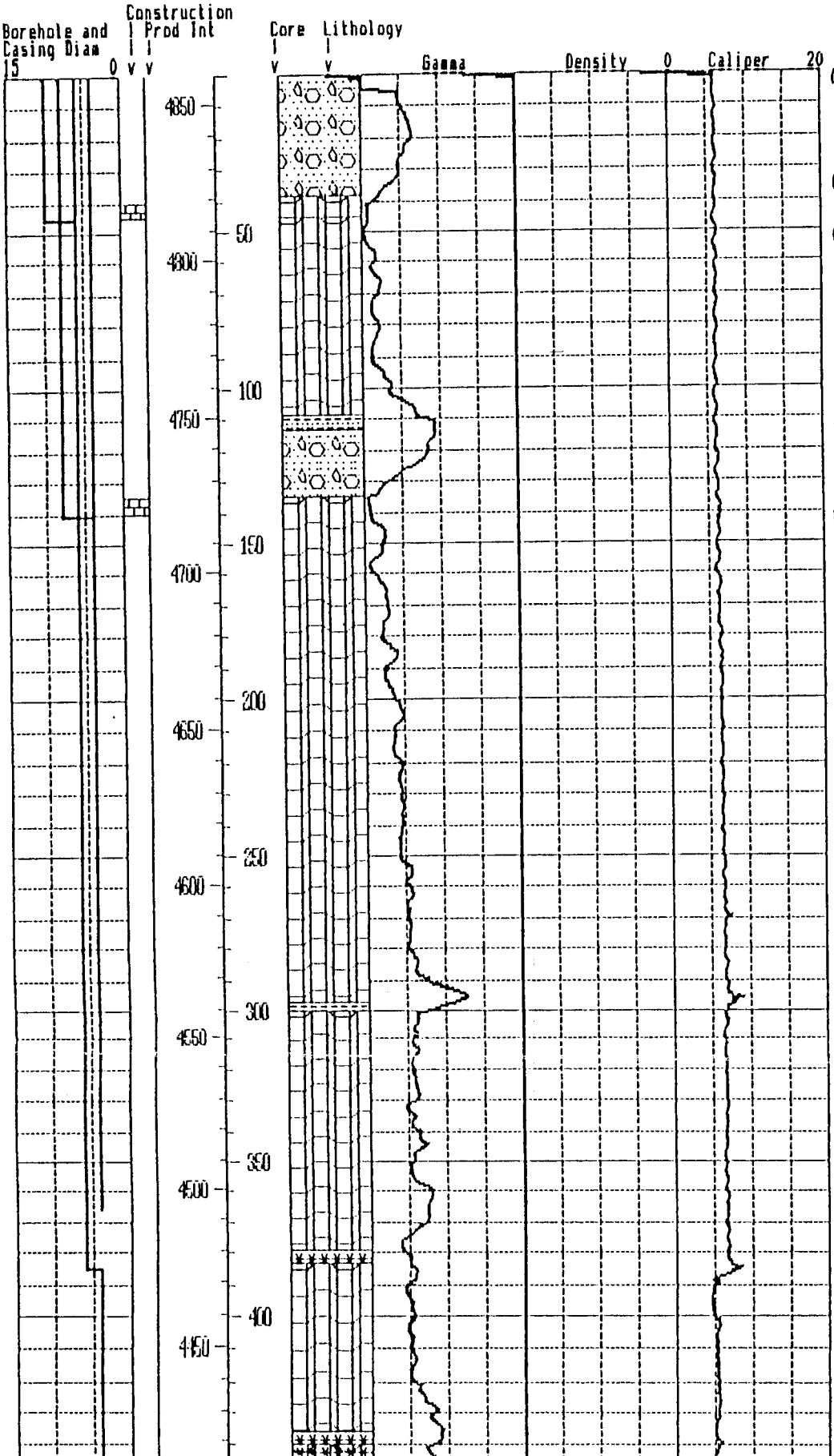
(170-187) CLAY:BASALT

(187-357) BASALT with clay at 194-203, 299-301 and 345-354

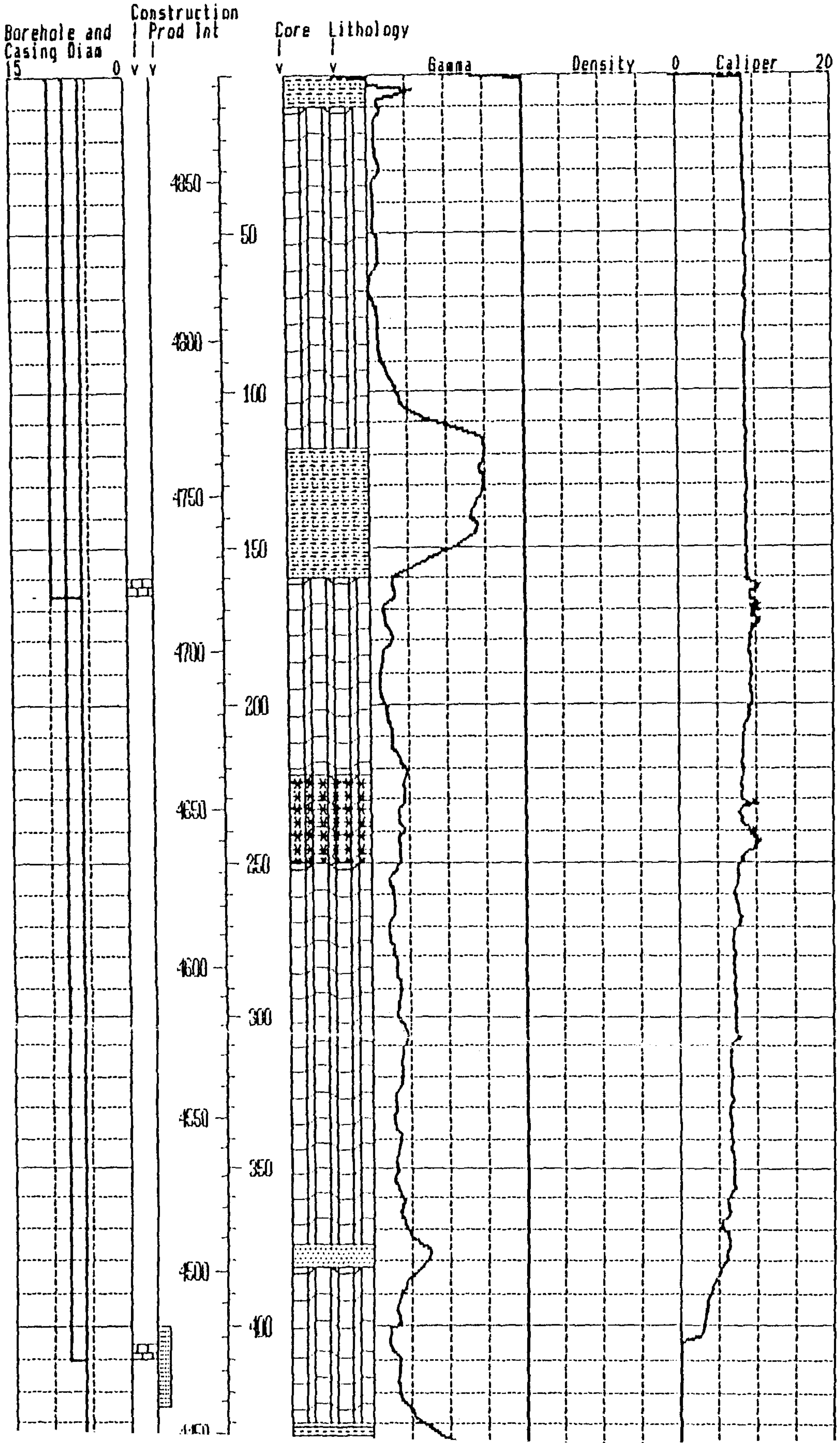
(357-391) FRACTURE broken basalt

(391-637) BASALT with broken basalt/clay at 515-521 and clay at 612-622

WELL: USGS-097



WELL: USGS-098



Description

(0-10) SILT:SANDY

(10-118) BASALT

(118-160) SILT:SANDY

(160-222) BASALT, grouted at 160-165

(222-250) BASALT:CINDERS, with sand

(250-382) BASALT with sand in-filling at 375-382

(382-430) BASALT, grouted at 405-410

(430-450) CLAY:SILTY